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Probable Maximum Precipitation and Snowmelt Criteria for Southeast Alaska

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TABLE OF CONTENTS

Page

Page

LIST OF FIGURES

LIST OF TABLES

PROBABLE MAXIMUM PRECIPITATION AND SNOWMELT CRITERIA FOR SOUTHEAST ALASKA

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ABSTRACT. This study gives probable maximum precipitation (PMP) estimates for durations between 6 and 72 hours for area sizes between 10 and 400 mi^2 (26 and 1036 km^2) for any location in Southeast Alaska (except for the extreme northwest section). In addition to all-season PMP, estimates are provided for the spring and early summer snowmelt season.

This study also provides generalized estimates of snowpack and other snowmelt criteria including temperatures, dew points, and winds. A stepwise procedure is included showing how the information developed may be used.

1. INTRODUCTION

1.1 Background

Over a considerable span of time, numerous estimates of probable maximum precipitation (PMP) for Alaska have been made for individual basins. These studies involved a variety of approaches, particularly in regard to handling the orographic problem in a region greatly deficient in data. Some of the specific unpublished basin estimates since 1960 include the Bradley Lake Basin (54 mi^2, 140 km^2) in 1961, the Chena River Basin (2,070 mi^2, 5,361 km^2) in 1962, the Long Lake Basin (30.2 mi^2, 78 km^2) in 1965, the Takatz Creek Basin (10.6 mi^2, 27 km^2) in 1967, four small basins near Ketchikan in 1974, and four larger basins of the Susitna River Drainage ranging in size from 1,260 mi^2 (3,263 km^2) to 5,840 mi^2 (15,126 km^2) in 1975.

In 1966, a more comprehensive study including generalized snowmelt criteria was done for the Yukon River Basin above Rampart Dam site (200,000 mi^2, 518,000 km^2) (U.S. Weather Bureau 1966). A generalized PMP report for all of Alaska provided all season estimates for areas up to 400 mi^2 (1,036 km^2) and durations to 24 hours (Miller 1963). Since that report provided estimates for the entire State, it did not provide detailed results for any particular region. The present report concentrates on a small portion of the State, the southeastern portion only, and presents more detailed estimates of PMP. The study area is the portion of southeast Alaska that is south of a line that extends northeastward from the coast at 58°45'N to the Canadian border (fig. 1).

1.2 Assignment

The authorization for generalized meteorological criteria was given in a memorandum from the Corps of Engineers (COE) dated February 10, 1976. First priority was given to the development of generalized all-season PMP values. Next a study was to be conducted giving spring and early summer PMP estimates and necessary criteria for developing the snowmelt flood.

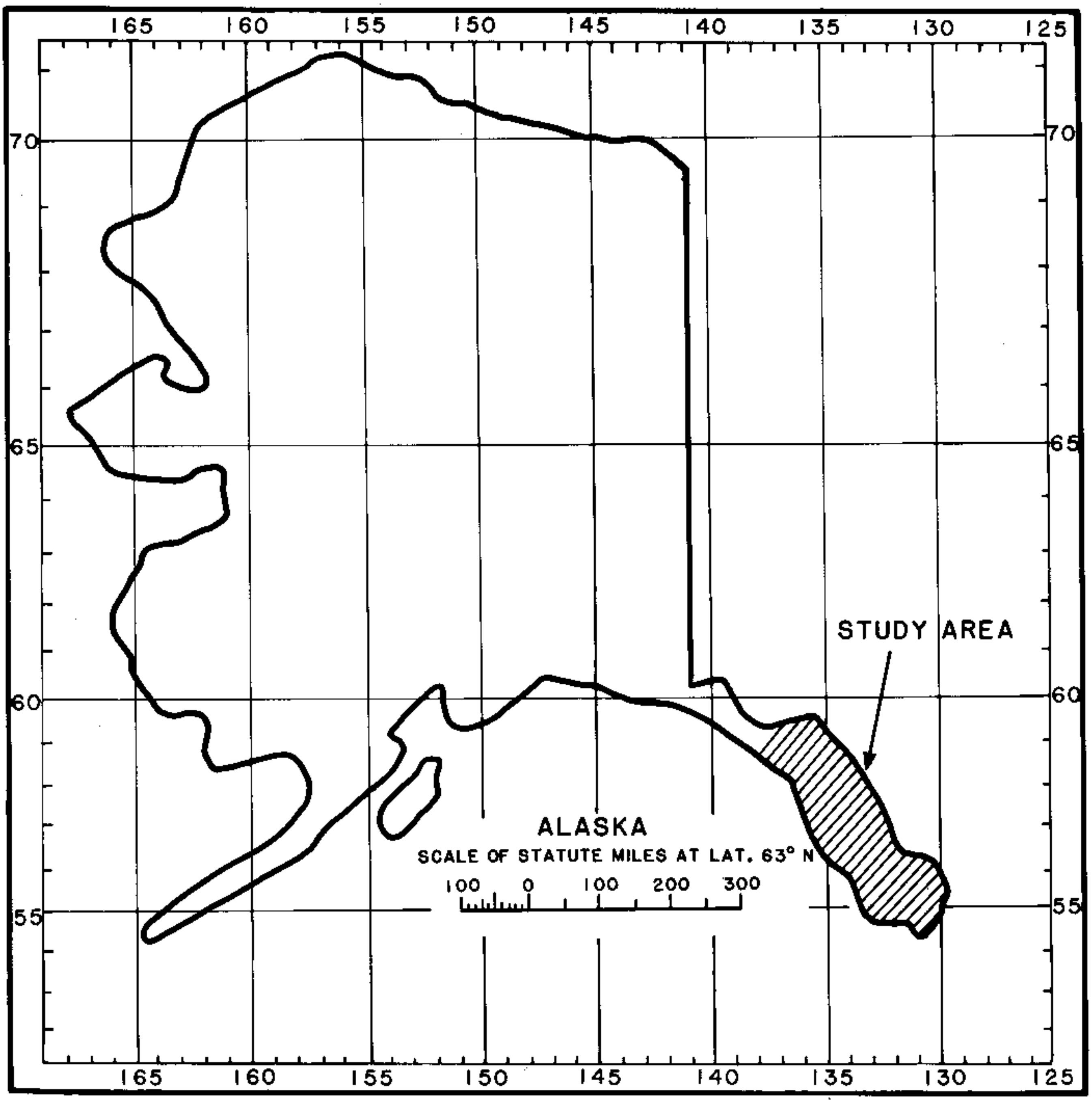

Figure 1.--Alaska showing the study area.

1.3 Approach to Probable Maximum Precipitation

In developing an approach to preparing generalized PMP estimates for a region like southeast Alaska, two factors must be considered. One is the complicated topography of the region. The second is the sparsity of daily or hourly precipitation measurements. Most of these measurements have been made within the first few hundred feet near the coastlines of the various islands or along the numerous bays and estuaries. Data are nearly nonexistent for the remaining 70 percent of the basin which is above 500 ft (152 m) (fig. 2). These conditions required developing and adopting relations from other regions and using other indicies of precipitation magnitude.

Annual streamflow data were combined with available precipitation data to develop a mean annual precipitation (MAP) chart. This along with analysis of small glaciers and snowpack-accumulation season was used as guidance to delineation of generalized PMP estimates. Relations of MAP to PMP in the Northwest States (U.S. Weather Bureau 1966) were developed and adjusted to the PMP magnitude determined as appropriate for the study. A second approach was based on relations between storm precipitation and PMP in the Northwest States region. A first approximation of generalized PMP was developed first from these two relations and then adjusted by a variety of techniques to provide the basic 24-hr, 10-mi^2 (26-km^2) PMP map. Depth-duration relations were generalized to provide estimates for durations to 72 hours and areas to 400 mi^2 (1,036 km^2). Seasonal variation factors (to cover the spring snowmelt season) were also developed for the period from May 15 to October 1.

1.4 Format of Report

Chapter 2 is devoted to the development of the MAP. A portion of this development involved a relation between MAP and the variation of the snow accumulation season with elevation.

The development of 24-hr, 10-mi^2 PMP (26-km^2) is covered in chapter 3. It includes the generalized depth-area-duration relation of PMP. The seasonal variation of PMP to cover the snowmelt season is also discussed.

Chapter 4 covers generalized criteria for the snowmelt flood. Included are maximum snowpack, and sequences of critical snowmelting temperature, dew points, and winds.

2. DEVELOPMENT OF GENERALIZED MEAN ANNUAL PRECIPITATION MAP

2.1 Introduction

2.1.1 The Problem

Our study region is one with quite varying and complicated topography with islands and peninsulas that form part of mainland North America, separated by bodies of water of varying extent. A useful MAP analysis must assess the effects of the complicated terrain. To do this, one needs to go beyond the limited precipitation data, particularly for the data-sparse higher elevations.

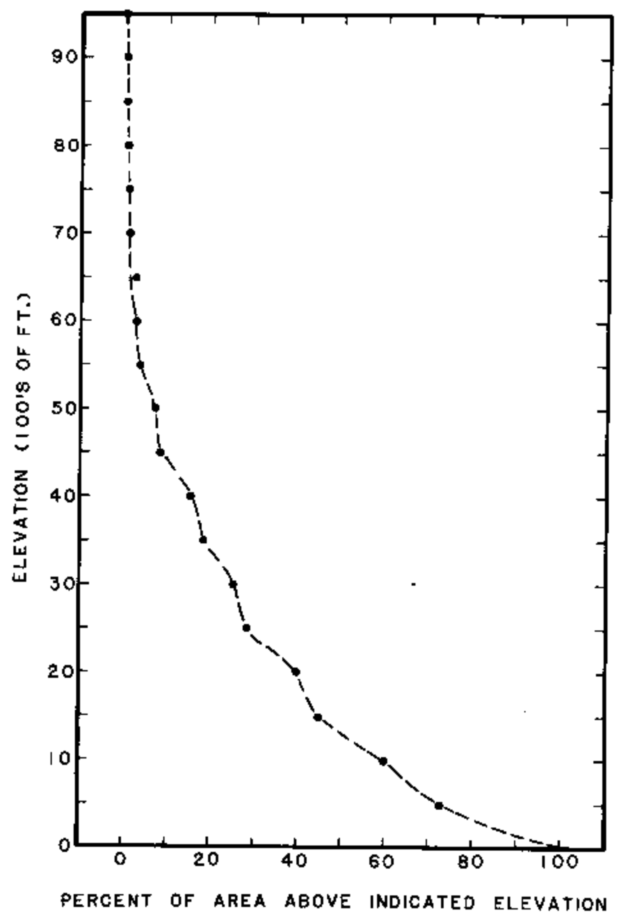

Figure 2.—Area-elevation curve.

2.1.2 Previous Studies

We reviewed two earlier MAP charts that exist covering our study area. One for southeast Alaska (Thompson 1947) was "based on sea level conditions." Although mean annual streamflow values were plotted on Thompson's map, he did not use them to estimate MAP in the mountains.

The other chart (Kilday 1974) used stations with 10 or more years of precipitation records. All of Alaska is included in Kilday's MAP chart. An isoline interval of 80 in. (2,032 mm) is used on Kilday's map for most of our study area.

2.1.3 Degree of Detail

In the present study, we concentrate on a small southeast portion of Alaska. Both this "narrowing-in" on a limited portion of Alaska and the maximum use of streamflow data justify more detail than was provided in the previous reports. The real question becomes how much detail can be justified when reliance is partially based on approximate relations with streamflow data. Another aspect of the question on detail is the need for consistency from location to location. Somewhat data-rich areas, such as those surrounding Juneau and Ketchikan, display more variability in MAP than we show on our MAP chart. However, our inability to define similarly detailed variability in less data-rich areas and the desire for consistency both suggest a lesser degree of detail across the study area than that possible in the most data-rich areas. The tremendously complicated topography (about one-half the region is comprised of hundreds of islands of varying size) confirms the need for the emphasis on consistency of detail. Otherwise, we would be going overboard in attempting detail not justified by the data or the present state of knowledge concerning orographic effects on precipitation.

2.2 Data

2.2.1 Precipitation Data

The basic precipitation data for the study area are obtained almost exclusively from low-elevation stations. These show considerable variation from station to station, both in length of record and in the specific periods covered. We adjusted the station annual precipitation values to a common period. We chose the 30-yr period used for climatological normals, 1941-70. Station information and MAP values used are shown in table 1 and the station locations are plotted on figure 3. Since these are based upon the 30-yr period for 1941-70, the number of years of record shown in table 1 do not necessarily represent the period of record used for a particular station. For example, if an existing station with a long record actually has annual precipitation values for a total of 50 years, only the standardized 1941-70 period is used for the development of the MAP chart. Also, adjusting or normalization of a station's precipitation to the 1941-70 period in some cases involved only a few common years of record. The adjustment was done using the ratio method and nearby stations. Care was taken to maintain as similar topographic settings between stations as possible.

2.2.2 Streamflow Data

Table 2 lists the streamflow data used. Figure 4 shows outlines of the basins considered while the gaging locations were shown on figure 3. The first column in table 2 shows the U.S. Geological Survey's officially assigned gage numbers where available for the various sites. Where officially assigned numbers were not available, we assigned numbers based on the alphabetical listing. For example, number 9, Crater Creek at Port Snettisham, is simply the ninth basin listed in table 2. Where an average basin elevation was readily available, it is given in table 2. Since limited use was made of this elevation information, it was not determined for those basins where it was not available.

In the development of the MAP chart, basins that were about one-third or more covered with glaciers were of particular interest in a procedure used for estimating MAP. Hence, a column in table 2 shows the percent of the basin glacier-covered where this was estimated to comprise 30 percent or more of the drainage. Where the estimated amount is less than 30 percent, dashes are shown in table 2.

2.2.3 Snow Course Data

A limited amount of snow course data was also available for the region. Table 3 identifies the various snow course sites for which some data were available (U.S. Department of Agriculture, 1920 --) for help in the development of the MAP map. Some of these snow courses are no longer currently in use.

Table 1.—Mean annual precipitation data for southeast Alaska stations

Station	Lat. (°)	Lat. (')	Long. (°)	Long. (')	Elevation ft.	Elevation m	Length of period	Record years*	MAP in.	MAP mm	Remarks
Angoon	57	30	134	35	35	11	1923–74	37	38	965	Breaks
Annette	55	02	131	34	110	34	1941–74	33	114	2896	
Annex Creek	58	19	134	06	24	7	1917–74	58	114	2896	
Auke Bay	58	23	134	38	42	13	1963–74	11	62	1575	
Baranof	57	05	134	50	20	6	1937–63	26	147	3734	Breaks
Beaver Falls	55	23	131	28	35	11	1948–74	27	151	3835	
Bell Island	55	55	131	35	10	3	1930–52	21	109	2769	Breaks
Calder	56	10	132	27	20	6	1917–31	13	112	2845	Breaks
Canyon Island	58	33	133	41	85	26	1936–44	9	61	1549	
Cape Decision	56	00	134	08	39	12	1941–73	33	77	1956	
Cape Spencer	58	12	136	38	81	25	1937–74	38	105	2667	
Chicagof	57	40	136	05	10	3	1952–57	6	130	3302	
Coffman Cove	56	01	132	49	10	3	1971–74	4	98	2489	
Craig	55	29	133	09	15	5	1937–53	17	111	2819	
Davis R	55	46	130	11	22	7	1933–36	4	102	2591	
Eldred Rock	58	58	135	13	55	17	1944–73	27	46	1168	Breaks
Five Finger L.S.	57	16	133	37	70	21	1944–74	31	56	1422	
Fortmann Hatchery	55	36	131	25	132	40	1915–27	13	150	3810	
Fort Tongass	54	50	130	35	20	6	1868–70	2	122	3099	Breaks
Glacier Bay	58	27	135	53	50	15	1966–74	9	81	2057	
Guard Island	55	27	131	53	20	6	1944–69	24	66	1676	Breaks
Gull Cove	58	12	136	09	18	5	1923–52	15	99	2515	Breaks
Gustavus, FAA	58	25	135	42	22	7	1923–68	32	54	1372	Breaks
Haines Terminal	59	16	135	27	175	53	1958–74	17	50	1270	
Hollis	55	28	132	40	15	5	1953–62	10	103	2616	
Hyder	55	57	130	02	20	6	1937–40	4	78	1981	
Jualin	58	49	135	02	710	216	1928–29	2	70	1778	
Jumbo Mine	55	13	132	30	1500	457	1917–19	2	196	4978	
Juneau City	58	18	134	24	25	8	1917–72	56	93	2362	
Juneau WBAP	58	22	134	35	12	4	1943–74	32	54	1372	
Kake	56	59	133	57	8	2	1919–74	14	56	1422	Breaks
Kasaan	55	38	132	34	28	9	1919–41	15	86	2184	Breaks
Ketchikan	55	21	131	39	15	5	1917–74	58	162	4115	
Killisnoo	57	27	134	32	25	8	1923–24	2	56	1422	
Klawock	55	36	133	06	20	6	1930–31	2	94	2388	

Table 1.—Mean annual precipitation data for southeast Alaska stations (Continued)

Station	Lat. (°)	Lat. (')	Long. (°)	Long. (')	Elevation ft.	Elevation m	Length of period	Record years*	MAP in.	MAP mm	Remarks
Klukwan	59	24	135	54	91	28	1917–19	3	21	533	
Lincoln Rock L. S.	56	03	132	46	25	8	1944–67	23	64	1626	Breaks
Linger Longer	59	26	136	17	700	213	1963–74	11	34	864	Breaks
Little Port Walter	56	23	134	39	14	4	1937–74	38	222	5639	
Moose Valley	59	25	136	03	400	122	1946–57	12	31	787	
Pelican	57	57	136	14	75	23	1967–74	8	127	3225	
Perserverance Camp	58	18	134	20	1400	427	1917–20	4	155	3937	
Petersburg	56	49	132	57	50	15	1927–74	43	106	2692	Breaks
Point Retreat Light	58	25	134	57	20	6	1946–72	26	71	1803	
Port Alexander	56	15	134	39	18	5	1949–62	14	176	4470	Breaks
Radioville	57	36	136	09	15	5	1936–51	15	100	2540	
Salmon Creek Beach	58	19	134	28	20	6	1917–20	4	90	2286	
Seclusion Harbor	56	33	134	03	20	6	1933–41	9	115	2921	
Shelter Island	58	23	134	52	10	3	1926–30	5	55	1397	
Shrimp Bay	55	48	131	22	25	8	1915–16	2	99	2515	
Sitka, FAA	57	04	135	21	15	5	1951–74	24	89	2261	
Sitka Magnetic	57	03	135	20	67	20	1917–74	57	96	2438	Breaks
Speel River	58	08	133	44	15	5	1917–30	11	139	3531	Breaks
Strawberry Point	58	14	135	38	-	-	1923–25	3	53	1346	
Sulzer (Hydaburg)	55	12	132	49	25	8	1917–28	7	142	3607	Breaks
Tenakee Springs	57	47	135	15	20	6	1950–73	5	60	1524	Breaks
Treepoint Light Stn.	54	48	130	56	36	11	1930–70	39	98	2489	
View Cove	55	04	133	04	13	4	1932–46	15	165	4191	
Wrangell	56	28	132	23	37	11	1918–74	55	80	2032	

*Actual number of years for which annual precipitation was available. All data were adjusted to the equivalent of a record for the period 1941–70.

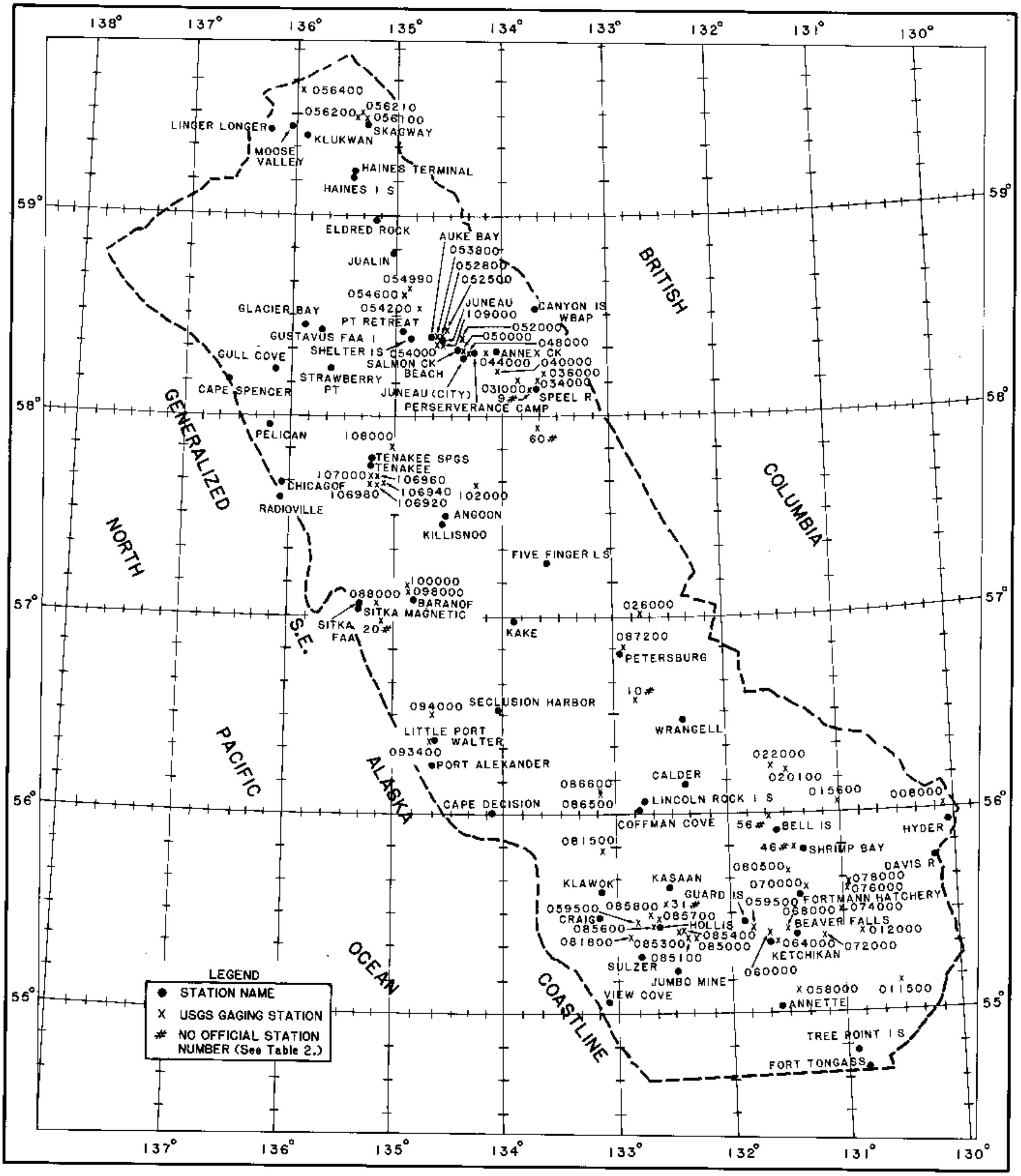

Figure 3.—Location of precipitation stations and stream gages.

Table 2.—Streamflow data used in development of mean annual precipitation map

Gage numbers*	Basin name	Gage Location Lat. (°)	Lat. (')	Long. (°)	Long. (')	Average elevation of drainage ft.	m	Drainage area mi^2	km^2	Mean runoff in.	mm	Years of record	Portion of drainage (in tenths) covered by glaciers**
054000	Auke C. at Auke Bay	58	23	134	38	1,160	354	4	10	59	1499	15	--
098000	Baranof River at Baranof	57	05	134	51	2,000	610	32	83	184	4674	27	--
086600	Big C. nr. Point Baker	56	08	133	09	680	207	11	29	110	2794	11	--
054600	Bridget Cove trib. nr. Auke Bay	58	37	134	56	400	122	1	3	45	1143	3	--
085300	Cabin C. nr. Kasaan	55	25	132	29	N/A	N/A	9	23	133	3378	2	--
044000	Carlson C. nr. Juneau	58	19	134	10	2,200	671	24	62	185	4699	10	--
026000	Cascade C. nr. Petersburg	57	00	132	47	3,160	963	23	60	149	3785	38	--
056400	Chilkat R. at gorge nr. Klukwan	59	38	135	55	4,820	1469	190	492	85	2159	5	.6
#9	Crater C. at Port Snettisham	58	08	133	46	N/A	N/A	12	31	222	5639	12	--
#10	Crystal C. nr. Petersburg	56	36	132	50	N/A	N/A	2	5	92	2337	13	--
054990	Davis C. nr. Auke Bay	58	39	134	53	2,540	774	15	39	95	2413	3	--
094000	Deer Lake Outlet nr. Point Alexander	56	31	134	40	1,300	396	7	18	291	7391	16	--
040000	Dorothy C. nr. Juneau	58	14	134	02	3,100	945	15	39	128	3251	36	--
074000	Ella C. nr. Ketchikan	55	30	131	01	900	274	20	52	173	4394	22	--
070000	Falls C. nr. Ketchikan (Swan Lake)	55	37	131	21	1,800	549	37	96	171	4343	28	--

*Number assigned by U.S. Geological Survey unless otherwise indicated (see Appendix A).
**Dashes in this column indicate less than 0.3 glaciers covered.
N/A not available.
#Station number assigned for this station as no official station number exists, data from Federal Power Commission. (see Appendix A).

Table 2.—Streamflow data used in development of mean annual precipitation map - Continued

Gage numbers*	Basin name	Gage Location Lat. (°)	Lat. (')	Long. (°)	Long. (')	Average elevation of drainage ft.	m	Drainage area mi^2	km^2	Mean runoff in.	mm	Years of record	Portion of drainage (in tenths) covered by glaciers**
109000	Fish C. nr. Auke Bay	58	20	134	35	1,600	488	14	36	78	1981	16	—
072000	Fish C. nr. Ketchikan	55	24	131	12	1,300	396	32	83	179	4547	56	—
050000	Gold C. at Juneau	58	18	134	24	2,400	732	10	26	149	3785	31	—
078000	Grace C. nr. Ketchikan	55	39	130	07	1,500	457	30	78	188	4775	16	—
#20	Green Lake at Silver Bay nr. Sitka	56	59	135	05	N/A	N/A	31	80	129	3277	10	—
087200	Hammers Slough at Petersburg	56	48	132	57	N/A	N/A	1	3	88	2235	3	—
022000	Harding R. nr. Wrangell	56	13	131	38	2,400	732	67	174	148	3759	22	.3
085700	Harris R. nr. Hollis	55	28	132	42	1,400	427	29	75	120	3048	15	—
102000	Hasselborg C. nr. Angoon	57	40	134	15	1,200	366	56	145	78	1981	16	—
054200	Herbert R. nr. Auke Bay	58	32	134	48	2,820	860	57	148	135	3429	5	.8
106940	Hook C. above trib.	57	41	135	08	1,260	384	4	10	94	2388	7	—
106960	Hook C. nr. Tenakee	57	41	135	10	1,160	354	8	21	71	1803	8	—
085600	Indian C. nr. Hollis	55	27	132	42	1,000	305	9	23	132	3353	15	—
106920	Kadashan R. above Hook C.	57	40	135	11	1,020	311	10	26	88	2235	6	—
107000	Kadashan R. nr.Tenakee	57	42	135	13	970	296	38	98	85	2159	10	—
#31	Karta R. at Karta Bay	55	33	132	35	N/A	N/A	49	127	126	3200	7	—
064000	Ketchikan C. at Ketchikan	55	21	131	38	1,280	390	14	36	207	5258	10	—
015600	Klahini R. nr. Bell Island	56	03	131	03	2,790	850	58	150	125	3175	6	—
053800	Lake C. at Auke Bay	58	24	134	38	1,170	357	3	8	70	1778	10	—
052000	Lemon C. nr. Juneau	58	24	134	25	3,430	1045	12	31	173	4394	21	.4
031000	Long R. above Long Lake	58	11	133	53	3,020	920	8	21	175	4445	9	.4
034000	Long R. nr. Juneau	58	10	133	42	2,400	732	33	85	192	4877	37	.4
068000	Mahoney C. nr. Ketchikan	55	26	131	31	1,680	512	6	16	260	6604	23	—
076000	Manzanita C. nr. Ketchikan	55	36	130	59	1,300	396	34	88	191	4851	30	—

Table 2.—Streamflow data used in development of mean annual precipitation map - Continued

Gage numbers*	Basin name	Gage Location Lat. (°)	(')	Long. (°)	(')	Average elevation of drainage ft.	m	Drainage area mi^2	km^2	Mean runoff in.	mm	Years of record	Portion of drainage (in tenths) covered by glaciers**
085800	Maybeso C. at Hollis	55	29	132	41	1,120	341	15	39	123	3124	14	--
052500	Mendenhall R. nr. Auke Bay	58	25	134	33	3,260	994	85	220	172	4369	9	.8
052600	Montana C. nr. Auke Bay	58	24	134	36	1,500	457	16	41	90	2286	9	--
081800	NB Trocadero C. nr. Hydaburg	55	22	132	52	1,050	320	17	44	119	3023	6	--
086500	Neck C. nr. Pt. Baker	56	06	133	08	500	152	17	44	99	2515	7	--
085100	Old Tom C. nr. Kasaan	55	24	132	24	1,000	305	6	16	86	2184	25	--
#48	Orchard C. at Shrimp Bay	55	50	131	27	N/A	N/A	59	153	132	3353	12	--
108000	Pavlof R. nr. Tenakee	57	51	135	02	900	274	24	62	91	2311	17	--
060000	Perserverance C. nr. Wacker	55	25	131	40	1,340	408	3	8	179	4547	31	--
058000	Purple Lake outlet nr. Metlakatla	55	06	131	26	860	262	7	18	176	4470	9	--
011500	Red R. nr. Metlakatla	55	08	130	32	1,700	518	45	117	177	4496	10	--
008000	Salmon R. nr. Hyder	56	02	130	04	3,900	1189	84	218	155	3937	10	.6
085000	Saltery C. nr. Kasaan	55	24	132	19	N/A	N/A	6	16	144	3658	2	--
093400	Sashin C. nr. Big Port Walter	56	23	134	40	1,130	344	4	10	284	7214	8	--
088000	Sawmill C. nr. Sitka (Medvetcha R.)	57	03	135	14	2,400	732	39	101	170	4318	28	--
048000	Sheep C. nr. Juneau	58	17	134	19	1,900	579	5	13	144	3658	34	--
#56	Shelokum Lake outlet at Bailey Bay	55	59	131	39	N/A	N/A	17	44	174	4420	9	--
056100	Skagway R. at Skagway	59	27	135	19	3,900	1189	145	376	47	1194	12	.4
036000	Speel R. nr. Juneau	58	12	133	37	3,100	945	226	585	157	3988	16	.4
081500	Staney C. nr. Craig	55	49	133	08	850	259	52	135	96	2438	10	--

Table 2.--Streamflow data used in development of Mean Annual Precipitation Map - Continued

Gage numbers*	Basin name	Gage Location Lat. (°)	Lat. (')	Long. (°)	Long. (')	Average elevation of drainage ft.	m	Drainage area mi^2	km^2	Mean runoff in.	mm	Years of record	Portion of drainage (in tenths) covered by glaciers**
#60	Sweetheart Falls Cr. at Pt. Snettisham	57	57	133	41	N/A	N/A	27	70	171	4343	10	--
056210	Taiya River nr. Skagway	59	31	135	21	4,820	1469	179	464	80	2032	5	.5
100000	Takatz C. nr. Baranof	57	09	134	52	2,300	701	18	47	202	5131	18	.3
106980	Tonalite C. nr. Tenakee	57	41	135	13	950	290	15	39	91	2311	5	--
080500	Traitors Creek nr. Bell Island	55	44	131	30	N/A	N/A	21	54	97	2464	3	--
020100	Tyee C. at mouth nr. Wrangell	56	13	131	30	2,620	799	16	41	148	3759	8	--
085400	Virginia C. nr. Kasaan	55	26	132	26	N/A	N/A	3	8	57	1448	2	--
056200	West C. nr. Skagway	59	32	135	21	3,400	1036	43	111	103	2616	12	--
059500	Whipple C. nr. Ward Cove	55	27	131	48	880	268	5	13	97	2464	6	--
012000	Winstanley C. nr. Ketchikan	55	25	130	52	1,730	527	16	41	138	3505	29	--

(See legend on page 1 of this table).

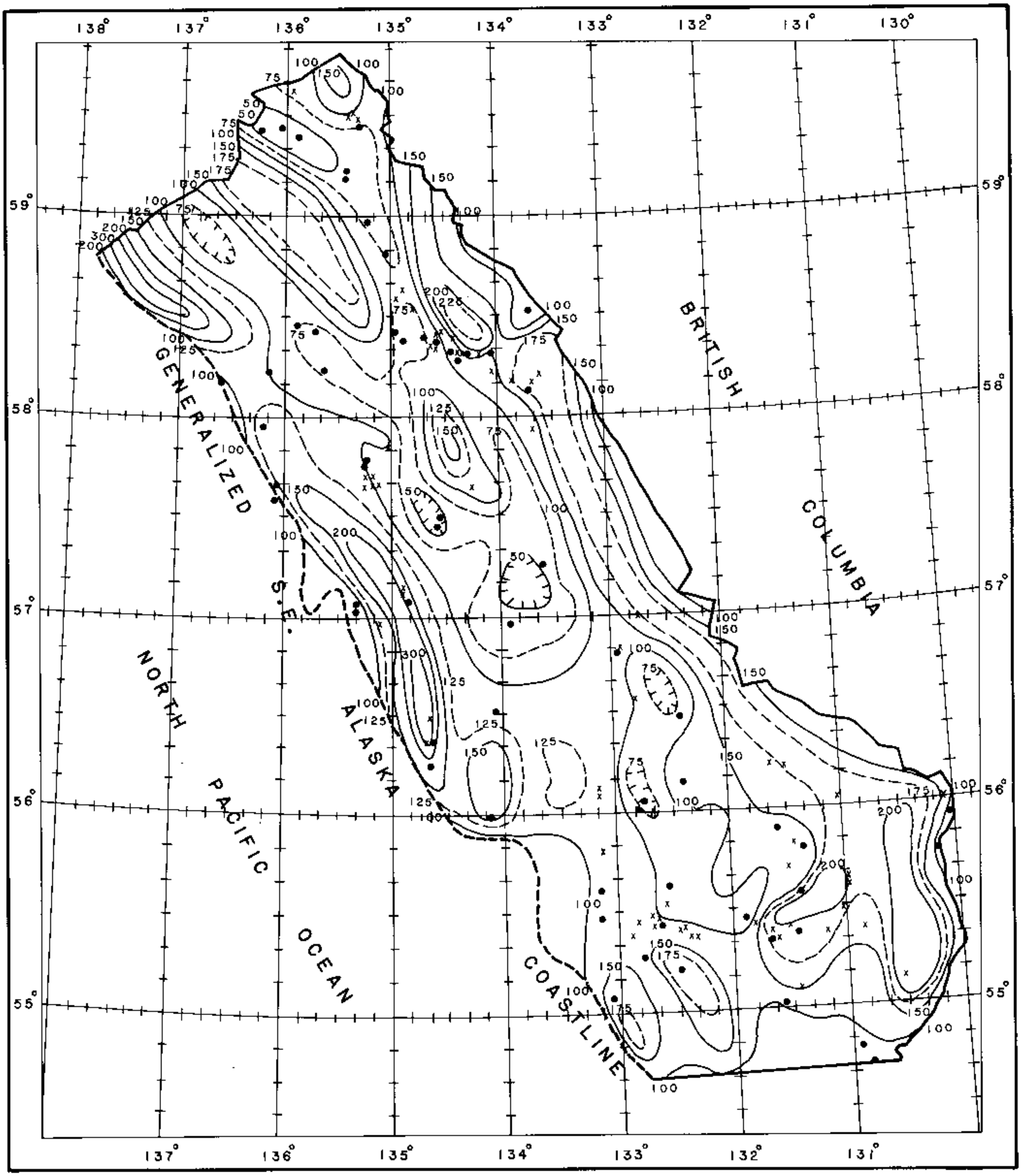

Figure 4.--Outline of basins whose data were used to aid in development of mean annual precipitation chart.

Table 3.—Location of snow course locations used in this study

Snow course name	Location: Lat. (°)	(')	Long. (°)	(')	Elevation: ft	m
Upper Long Lake	58	11	133	43	1,000	305
Long Lake	58	12	133	47	1,080	329
Speel River	58	09	133	43	280	85
Crater Lake	58	08	133	43	1,750	533
Harriet Top	55	29	131	37	2,000	610
Hunt Saddle	55	30	131	37	1,500	457
Lake Shore	55	29	131	36	660	201
Wolverine Glacier	60	25	148	55	4,430	1,350

2.2.4 Upper Air Temperature Data

Judgment on the magnitude of MAP for some locations came from analyses of small glaciated areas (sec. 2.4). For this analysis mean upper air temperatures at selected heights were used. The monthly temperature means for Juneau are tabulated in table 4 (Ratner 1957). These data were chosen as an upper air index to mean temperatures.

Table 4.—Mean upper air temperatures for Juneau (after Ratner, 1957)

Height (mb)	J	F	M	A	M	J	J	A	S	O	N	D
					Temperature °C*							
950	-6.6	-4.2	-1.4	1.8	6.6	10.6	12.0	11.7	9.4	4.3	-0.2	-3.1
900	-9.0	-6.4	-4.4	-1.4	3.3	7.1	8.9	8.8	6.6	1.5	-2.6	-5.5
850	-11.2	-8.6	-7.4	-4.7	0.2	4.1	5.7	5.8	3.6	-1.5	-5.1	-8.0
800	-13.1	-10.5	-10.1	-7.8	-2.7	1.2	3.0	3.0	1.0	-4.3	-7.3	-10.3

*°F can be determined from the equation $^{o}F = \frac{9}{5}\,(^{o}C) + 32$

2.3 First Approximation to Mean Annual Precipitation

The approach used consisted of: (a) deriving a first approximation MAP as described in this section, and (b) checking, and adjusting this analysis through a technique that uses the existence and/or nonexistence of small snowfields or glaciers as described in section 2.4.

2.3.1 Guidelines for First Approximation

The following guidelines were set up for the analysis of the MAP:

a. A primary aim was uniformity of detail.

   There are two alternatives. First, a detailed analyses would be completed in relatively data dense regions such as in the vicinity of Juneau, Ketchikan, and on a portion of Baranof Island (e.g., streamflow from several adjoining basins--see fig. 10). Then, in data sparse regions detailed analyses would be based on the limited data and topographic and meteorologic similarities. The second alternative would be to space average or smooth-out some of the variability shown by the data in the regions around Juneau, etc. This latter methodology was adopted for this study.

b. Where rainfall and streamflow measurements in close proximity appear to conflict, generally the rainfall measurements were given preference. This general preference rule was not applied inflexibly since, in concert with the first principle of consistency of detail, some locations with higher density of rain gage measurements (e.g., near Juneau) were not as useful in terms of smooth generalizations as were nearby streamflow measurements.

c. The overall losses due to transpiration, etc., are generally less in Southeast Alaska than in the contiguous United States. We assume this difference is the result of predominance of moist air masses in southeast Alaska which limit transpiration losses.

d. The degree of detail in the 1:1,000,000 scale topographic map was used for analysis of the MAP. Further smoothing is introduced by use of a generalized elevation chart (fig. 5).

2.3.2 Analysis

Following the guidelines in section 2.3.1 a chart of MAP was analyzed. The degree of smoothing around data-rich areas is evident if one looks at the plotted data and analyzed map (fig. 6) in areas near Juneau and Ketchikan. The uniformity of detail was aided by use of the generalized elevation contour analysis (fig. 5). This analysis was the primary orographic base used for the initial MAP analysis.

The first approximation map was closely drawn to most of the adjusted precipitation data (sec. 2.2.1). A few short-record precipitation stations with data that were from the years before 1930 were not amenable to adjustment to a 1941-70 normal, and so these carried less weight in the overall analysis. Shrimp Bay, near the southern end of our study area (fig. 3), with a 2-yr record (1915-16) was located in a region of relatively plentiful data and its MAP was enveloped. However, in a few cases (of short records) such as the 4-yr record at Davis River, useful information was provided for data-deficient areas. A qualitative relation with topography was maintained by using this as an underlay during the MAP analysis. Though precipitation data were inadequate to develop a specific quantitative elevation-precipitation relation, knowledge from other regions suggested some increase in MAP with elevation. This subjective relation is evident in the analyzed final chart (fig. 6).

Streamflow data provided an extremely valuable supplement to the precipitation data. Helping in this regard were: (a) a classification of quality of records, (b) a check on the stability of the records based upon their length, and (c) the

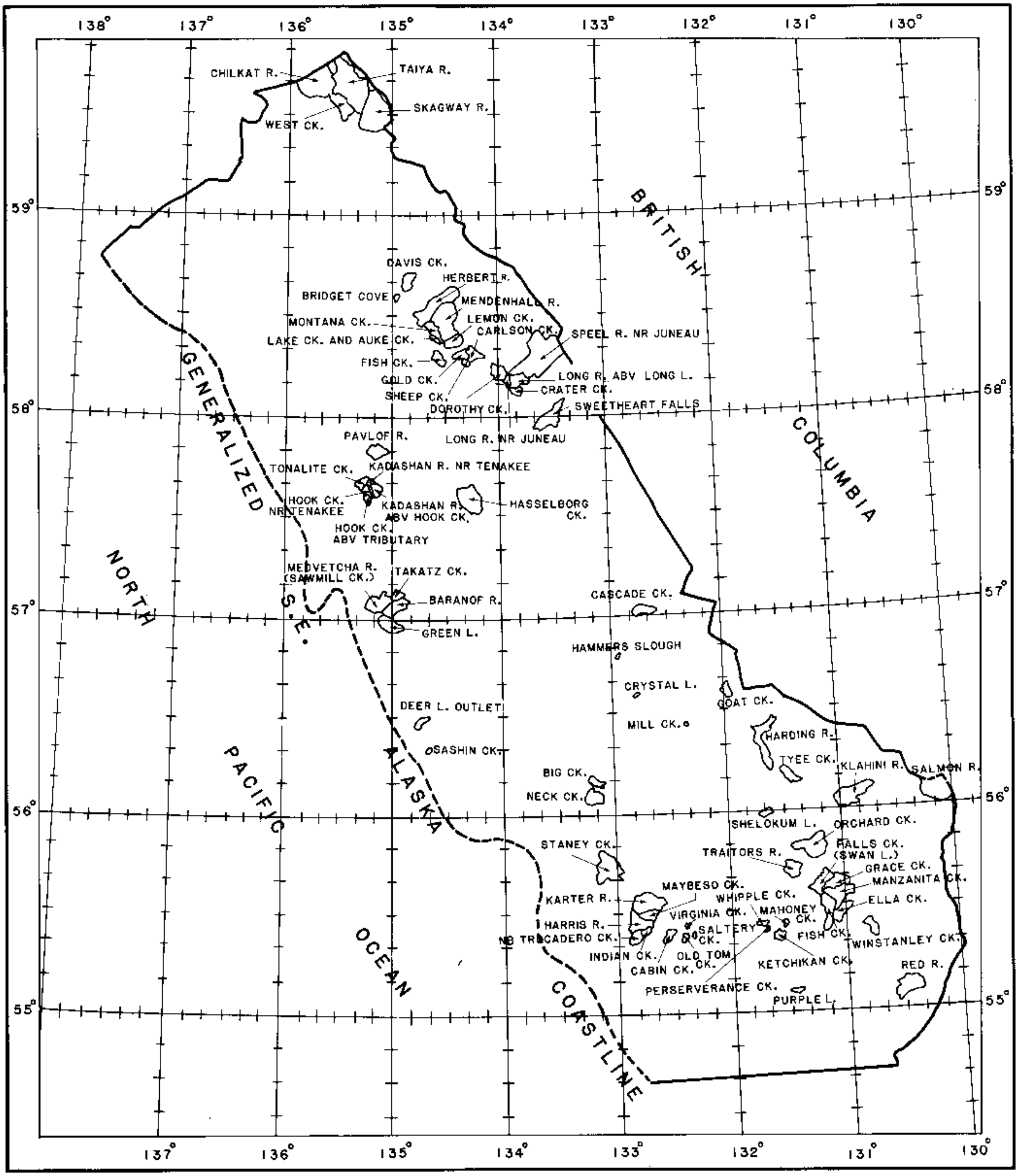

Figure 5.--Generalized evaluation contours for southeast Alaska. Labels are in 1000's of feet.

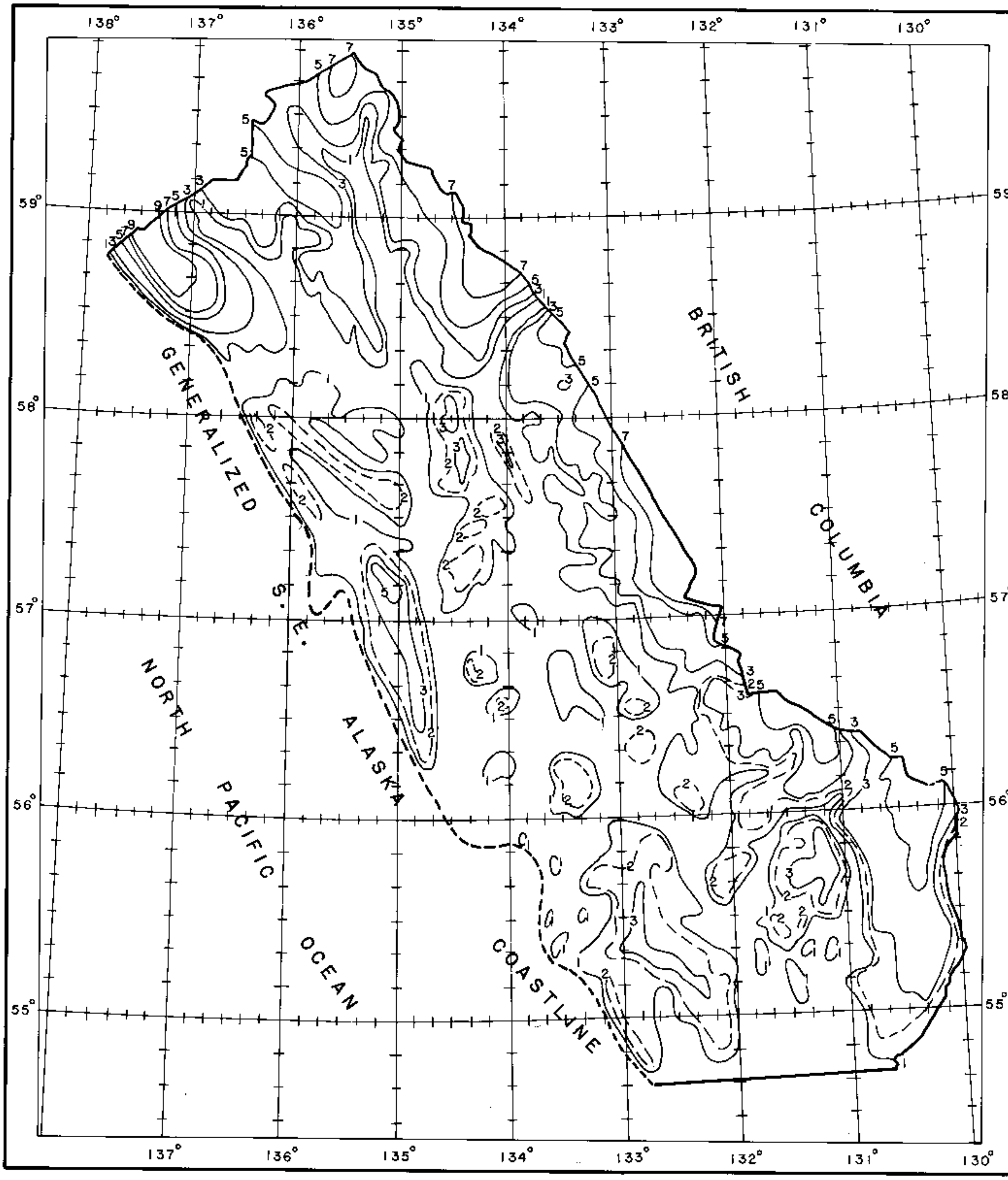

Figure 6.—Mean annual precipitation chart (inches) for southeast Alaska.

existence of streamflow records from stations in close proximity that have similar topography (e.g., fig. 10).

The Manzanita Creek drainage (see table 2), using the normalized record, showed a mean seasonal runoff of 191 in. (4851 mm). The nearby drainages of Ella Creek, Grace Creek, and Falls Creek (see fig. 4 for locations), all with shorter records, showed overall good consistency in magnitude of runoff in reference to existing orography. On the interior upslopes, streamflow data were limited, but still provided valuable information for analysis. For example, two drainages with rather long records, Cascade Creek (141 in., 3581 mm) and the Harding River (148 in., 3759 mm) near Wrangell, provided good consistency in this region where precipitation measurements were absent.

Even the short record streamflow data were generally of use, again mainly through evidence of internal consistency. For example, the 286-in. (7264-mm) runoff for a short 3-yr record at Deer Lake Creek outlet would, by itself, be of limited usefulness. However, the nearby 8-year record at Sashin Creek with runoff of 284 in. (7214 mm) provided valuable consistent support. Also, the MAP measured at the nearby station of Little Port Walter is 222 in. (5639 mm). These mean runoff and precipitation measurements with topographic considerations suggested an analysis that showed at least 300 in. (7820 mm) of MAP at the higher elevations in this portion of Baranof Island. The smoothed analysis resulted in an envelopment of the observed precipitation value for Little Port Walter.

The agreement of streamflow and precipitation data in the regions cited as well as in others where both were available supported the use of streamflow data alone as a reasonable lower limit where precipitation data were not available.

2.4 Adjustments to Mean Annual Precipitation Chart Based on Analysis of Data from Small Snow Fields or Glaciers

It was our opinion that massive glaciers are not good indicators of variations in MAP amounts at various elevations since snow accumulations at high elevations may move through glacial processes to considerably lower elevations. However, in Southeast Alaska there are, in addition to massive glaciers, numerous areas where relatively small snow fields, or glaciers, barely persist through the warm season. In spite of recognized uncertainties, such restricted snowfields may provide some help in making adjustments to first approximation estimates of MAP. The size and type of snow field selected are quite important to the technique. It must be small enough to be indicative of a "balance." By "balance" we mean the small snowfields or glaciers show that the accumulated snowpack just barely disappears, for all practical purposes, as a new seasonal snowpack begins to form in the fall. In addition to the careful selection of the type and size of small glaciers, two basic relations needed to be developed. These are:

a. A relation telling how much of the MAP normally can be expected to accumulate as snowpack, and

b. A relation telling how much snowpack can melt in a normal season.

Both relations depend significantly on elevation and prevailing temperatures. The development of the first relation involves two parts. First the length of accumulation period versus elevation was determined. Then values of MAP were introduced so that accumulation could be related to MAP. Thus, given a MAP and elevation for a particular location, one may obtain the snowpack. For development of the second relation, both empirical and theoretical approaches were used to relate snowmelt to season and elevation.

2.4.1 Accumulation Season Versus Elevation

This section describes how we approximated the length of the snow accumulation season as a function of temperature and elevation.

2.4.1.1 Temperature Data. Temperature data discussed in 2.2.4 were used to develop the variation in length of precipitation accumulation season versus elevation. Several simplifying assumptions are used in the development. These are:

a. The accumulation season, at a given elevation, is assumed to be defined as the period of the year during which the mean daily free air temperature is freezing (0°C or 32°F) or below.

b. The melt season starts (ends) the first day the mean daily temperature rises above (falls below) freezing.

c. All precipitation was assumed to accumulate in the snowpack during the accumulation season.

Figure 7 shows our analysis of the upper air temperature data used for determining the variation of accumulation season with elevation. From a temperature analysis at standard pressure levels, curves were drawn for the 1,000-, 2,000-, 3,000-, 4,000-, 5,000, and 6,000-ft (305-, 610-, 914-, 1,220-, 1,524 and 1829-m) levels (fig. 7). The accumulation seasons (rounded to half months) for these elevations are tabulated in table 5.

2.4.1.2 Precipitation Data. In order to work out the percentages of MAP to be assigned to the accumulation seasons of table 5, monthly precipitation data from nine stations were used (1941-70). Table 6 shows normal monthly precipitation values for each station and the sum for the nine stations. These monthly sums are then shown as a percent of the MAP for the nine stations. Both the airport data and the city office data at Juneau were used even though they are in close proximity, because large precipitation differences exist which reflect differing orographic effects. In spite of these differences, the monthly percents of MAP do not differ significantly for the two locations.

We then evaluated whether it was appropriate to use the monthly percents of MAP (of table 6) for all elevations. Monthly precipitation records were available for only two stations in southeast Alaska at elevations significantly above sea level. These were at Jumbo Mine (1,500 ft, 457 m) with a little over 3 years of record, and Perserverance Camp (1,100 ft, 335 m) with about a 7.5-yr record. Monthly means (percent of seasonal precipitation) were determined for these two short-record stations. These were within the range of the means for the nine stations used in table 6, except for August and November (higher percents) and

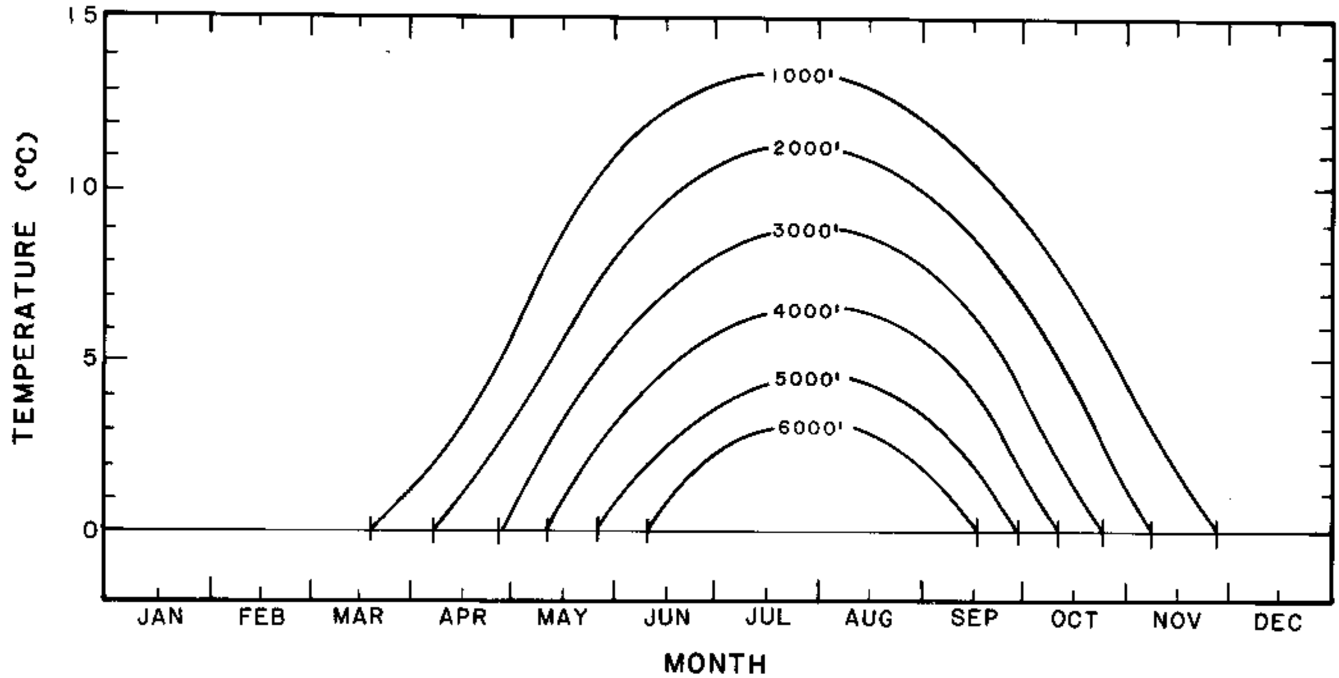

Figure 7.—Analysis of upper air temperature based upon Juneau (after Ratner).

Table 5.—Snowpack accumulation season

Height ft	m	Duration of accumulation season
1,000	305	December 1 - March 15
2,000	610	November 15 -April 15
3,000	914	November 1 - April 30
4,000	1220	October 15 - May 15
5,000	1524	October 1 - May 31
6,000	1829	September 15 - June 15

September (lower percents). The November value for Jumbo Mine differed most from the nine-station mean (table 6) because a single very large November value of 61.46 in. (1561 mm) in 1918 distorted November's monthly mean. Using the average precipitation of the other two years, the percentage for November is very close to the nine-station mean. We conclude the monthly percentage of mean annual precipitation (table 6) can be used for all elevations.

2.4.1.3 Accumulation Season Percentages Versus Elevation. The mean monthly percentages of table 6 were summed to determine the percent of MAP for the accumulation season (table 5) at each elevation. Where beginnings or endings of an accumulation period were at midmonth, one-half of that month's percentage contribution to the MAP were used in the summation. Results are shown in table 7.

Table 6.—Monthly contributions to mean annual precipitation

Station	Elevation ft	Elevation m		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
				Precipitation amount — Month												
Cape Spencer	81	25	in.	7.60	6.22	6.69	5.54	6.09	4.75	6.80	8.90	13.93	16.08	13.77	9.81	106.18
			mm	193	158	170	141	155	121	173	226	354	408	350	249	2697
Juneau No. 2	25	8	in.	6.89	6.16	6.42	5.99	5.61	4.09	6.43	7.61	11.03	13.36	10.00	8.39	91.98
			mm	175	156	163	152	142	104	163	193	280	339	254	213	2336
Juneau WSO (AP)	12	4	in.	3.94	3.44	3.57	2.99	3.31	2.93	4.69	5.00	6.90	7.85	5.53	4.52	54.67
			mm	100	87	91	76	84	74	119	127	175	199	140	115	1387
Ketchikan	15	5	in.	15.06	12.74	12.15	12.88	8.62	7.20	8.48	11.27	15.29	24.77	17.63	16.18	162.27
			mm	383	324	309	327	219	183	215	286	388	629	448	411	4122
Little Pt Walter	14	4	in.	20.65	17.51	16.33	14.33	11.58	8.13	9.06	13.48	24.06	34.32	26.78	24.99	221.22
			mm	525	444	415	364	294	207	230	342	611	872	680	635	5619
Peters-burg	50	15	in.	9.31	7.48	6.98	7.10	5.78	4.82	5.57	7.31	11.26	17.51	11.68	10.79	105.59
			mm	236	190	177	180	147	122	141	186	286	445	297	274	2682
Sitka Magnetic	67	20	in.	8.21	6.68	7.45	5.62	4.69	3.45	5.11	7.20	11.44	14.30	11.28	10.07	95.50
			mm	209	170	189	143	119	88	130	183	291	363	287	256	2426
Wrangell	37	11	in.	6.85	5.76	5.50	5.02	3.93	3.89	5.12	6.19	8.66	12.93	9.08	7.64	80.57
			mm	174	146	140	128	100	99	130	157	220	328	231	194	2046
Yakutat WSO (AP)	28	9	in.	10.36	9.28	9.57	7.65	8.02	5.68	8.46	10.81	15.45	19.52	14.80	12.86	132.46
			mm	263	236	243	194	204	144	215	275	392	496	376	327	3364
Sum - in.				88.87	75.27	74.66	67.12	57.63	44.94	59.72	77.77	118.02	160.64	120.55	105.25	1050.44
mm				2257	1912	1896	1705	1464	1141	1517	1975	2998	4080	3062	2673	26681
Mean % of mean annual				8.46	7.17	7.16	6.30	5.49	4.28	5.68	7.40	11.23	15.29	11.48	10.02	100

Table 7.—Accumulation season snowpack water equivalent in percent of mean annual precipitation

Elevation ft	Elevation meters	Snowpack water equivalent percent of MAP
1,000	305	29
2,000	610	42
3,000	914	51
4,000	1,220	61
5,000	1,524	71
6,000	1,829	79

Interpolation by elevation and MAP can be accomplished through figure 8. The sloping lines on this figure (inches of MAP) are the MAP values at the indicated elevations that would produce the snowpack (water-equivalent) values shown on the abscissa. As an example of its use at an elevation of 3,000 ft (914 m) a snowpack water equivalent of 100 in. (2540 mm) requires a MAP of 196 in. (4978 mm). This comes from dividing the 100 in. (2540 mm) by .51 (the .51 being the 3,000-ft, 914 m) accumulation season portion of the MAP from table 7).

2.4.2 Development of Melt Curve for Small Glaciated Areas

We define the melt curve as the relation of the potential snowmelt at each elevation that would exist if enough snow were available at that elevation for melting through the melt season. The melt season (see section 2.4.1.1) is assumed to be the season when the mean daily temperature is above 32°F (0°C). Thus, the melt season plus the accumulation season (see section 2.4.1.1) equals the entire year. For practical purposes, a melt curve for low elevations where the prevailing melt season is long is a theoretical or "potential" melt curve only. Not enough snow can accumulate at the lower elevations to survive the entire melt season. This is true (the melt curve is a theoretical curve only) for nearly all locations in the study area below about 2,000 ft (610 m). The exceptions, of course, would be those areas where glaciers flow to below 2,000 ft (610 m) or lower from higher elevations. Above about 3,000 ft (914 m), there are numerous areas where enough precipitation actually accumulates to permit melting for the full melt season. For such areas the melt curve then becomes an "actual" melt curve.

Our interest is in developing a melt curve for elevations between 2,000 ft (610 m) and 6,000 ft (1,829 m) as a supplement to streamflow and precipitation measurements for refining the MAP. The curve is actually developed down to 1,000 ft (305 m) since theoretical computations for low elevations can help in "firming up" the shape of such a curve above 1,000 ft (305 m).

2.4.2.1 Purpose:

The purpose of the melt curve is to use it with the information from figure 8 to do the following:

a. Estimate MAP, or revise first approximation MAP estimates, particularly in data-sparse areas in southeast Alaska.

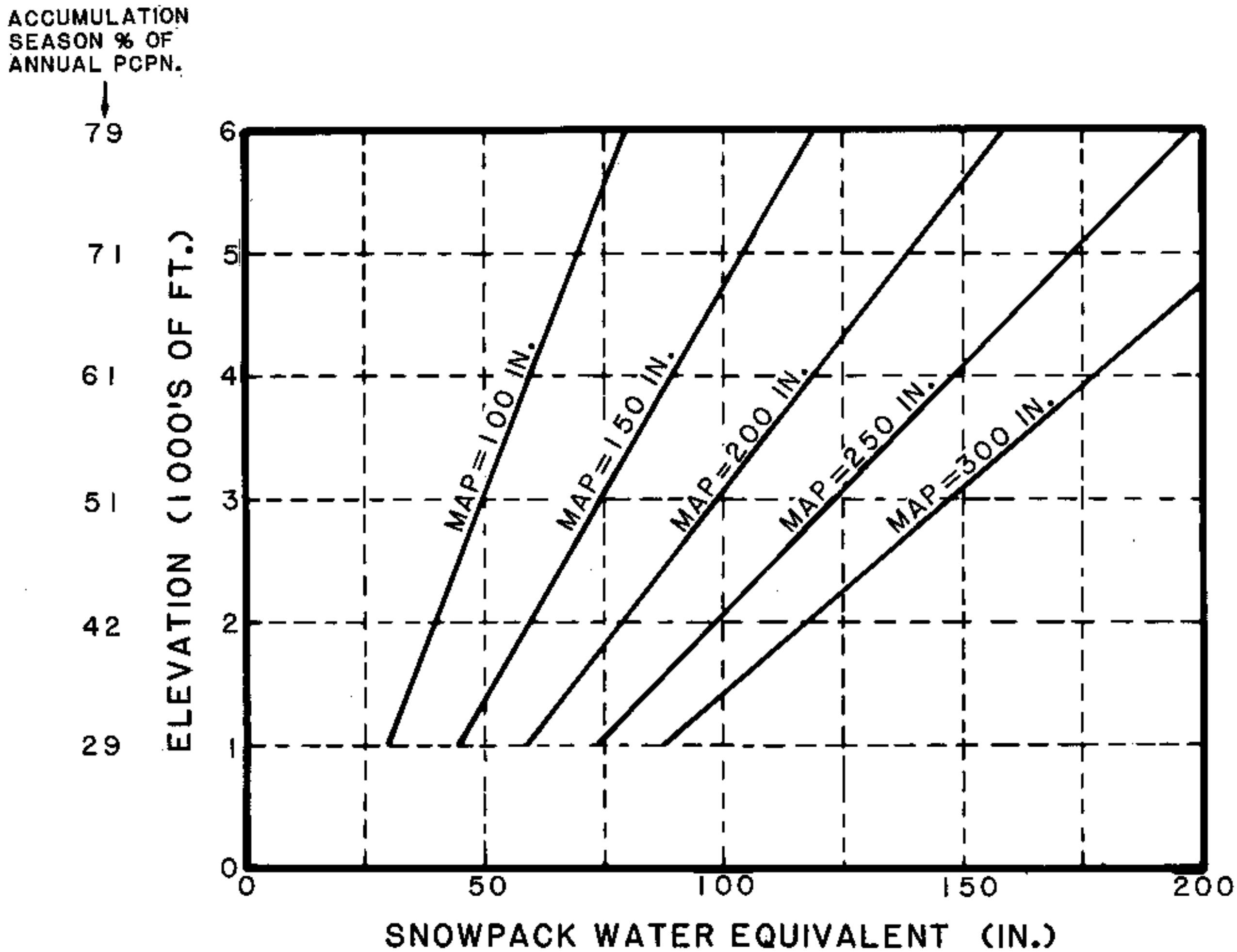

Figure 8.--Variation of snowpack water equivalent with elevation and mean annual precipitation.

b. Check the first approximation estimate on the basis of lack of small glaciated areas. That is, answer the question, "is the first approximation MAP too high in some areas?"

c. Check the first approximation estimate on the basis of the existence of small glaciated areas. Is it too low in some areas?

2.4.2.2 Definition of Usable Glaciated Areas. In order to be usable with the relation shown in figure 8 and to help define the melt curve, glaciated areas must have the following characteristics:

a. Ideally, such areas ought to be quite small, about 1 mi^2 (2.6 km^2) or less. This is necessary in order to assume that a balance exists, that is, in the mean, the accumulation of snow is just enough to provide all that can possibly melt.

b. If snowfields or small glaciers larger than 1 mi^2 (2.6 km^2) are used, great care must be exercised in their use and interpretation in terms of balanced conditions.

c. Usually when b. applies, and sometimes when a. applies, in order to determine whether or not particular areas qualify, detailed topographic maps are used to eliminate those cases where the terrain (e.g., narrow valleys with steep adjoining slopes) permit snowfields or small glaciated snow to collect or extend to unrealistically low elevations. By unrealistic we mean the snow extends to a lower elevation than that responsible for its formation and accumulation.

With the above criteria in mind, we need to recognize that a particular small glaciated or snow-covered area may qualify as an entity embracing a small elevation range or may qualify in part (i.e., not the whole area, even though small). It was necessary to use 1:63,360 scale topographic charts for appropriate definition of useable glaciated areas and for elevations.

2.4.2.3 Data Used in Development of Melt Curve. The data which played a part in the derivation of the melt curve consisted of the following:

a. Selected areas (mostly in the 3,000- to 5,000-ft or 914- to 1,524-m range in elevation) where an approximate "balance" between accumulated snowpack and melt could be substantiated by existing data.

b. Theoretical computations using a degree-day melt factor and free-air temperature data for the 950-mb level (a close-to-surface level where other types of data are deficient). This approach plus a composite of empirical data referred to below in c. provide the means of fixing of the curve at low elevations.

c. Corollary support both for amount of melt and shape of melt versus elevation curve came from free-air temperature, runoff, and snow course data.

2.4.2.4 Analysis with Empirical Fixes From "Balanced" Data-Supported Areas. Trapezoids were constructed from the supporting data for the positioning of the melt curve in the 3,000- to 5,000-ft (914- to 1,524-m) elevation range. Figure 9 illustrates this for the Baranof drainage. The inset shows four locations. Those identified as 1 and 2 are small areas (approximately 2 to 3 mi^2) that were selected randomly and show the range in elevations, MAP, and accumulated water equivalent values that could be found over small areas in southwest Alaska. To attempt to pin such data to points would be unrealistic. "A" and "B" on the inset identify the sample regions where "balanced" conditions exist as indicated by small perennial glaciers or snowfields. Snowfield A lies between a range of elevations from about 3,000 ft (914 m) to 5,000 ft (1,524 m). The size of this small glacier or snowfield, although not massive, is sufficiently great to cover this range of elevations, but the highest elevations to the windward of the

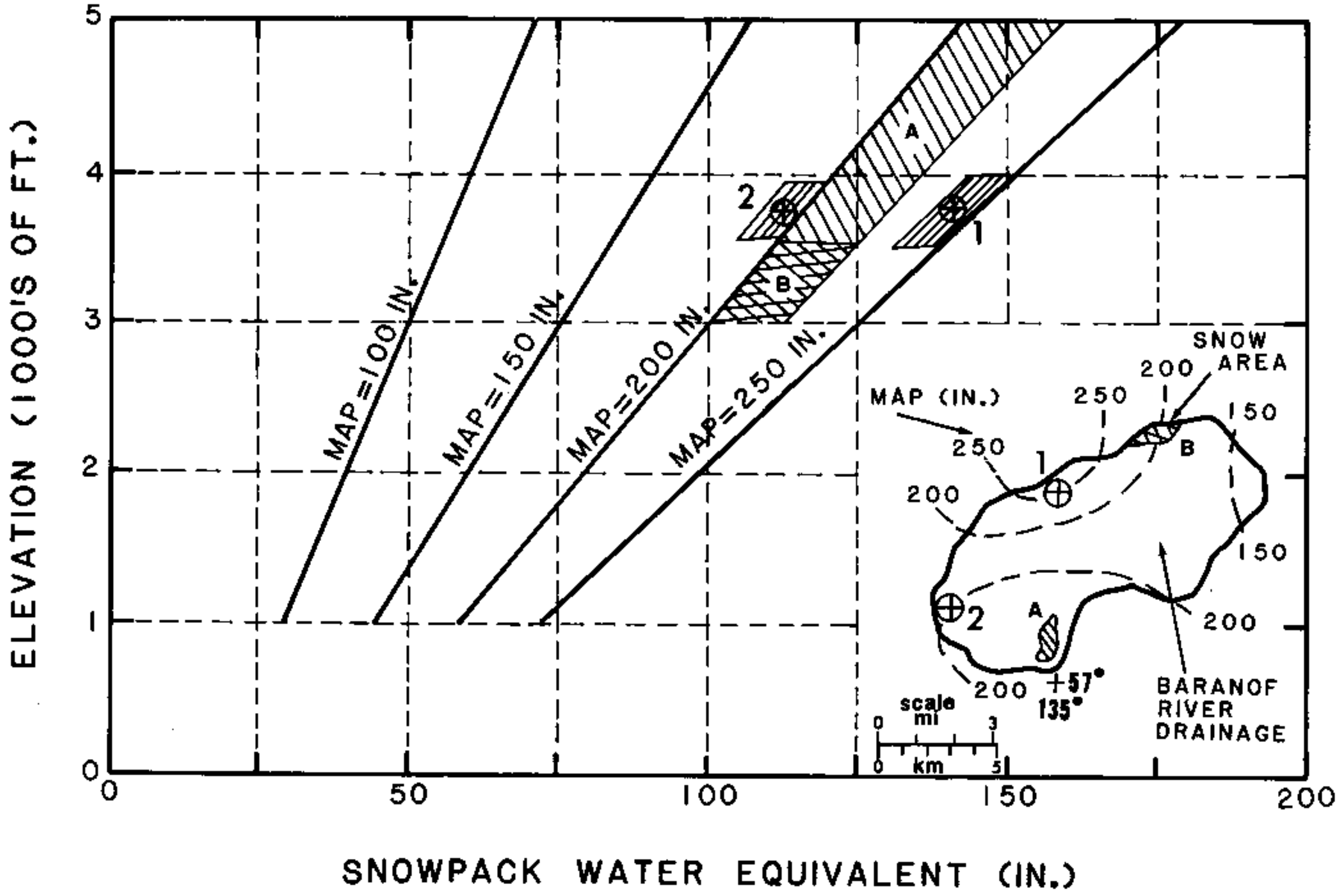

Figure 9.—Examples of parallelograms for balanced areas.

glaciers are likely most representative of the snow production. Area B with elevations of 3,500 to 4,000 ft (1,067 to 1,220 m) is overlapped by the larger elevation range of areà A. The assigned MAP values for the parallelograms were derived from the analysis of MAP over the Baranof River drainage and adjoining basins. How this more detailed analysis for the Baranof drainage and adjacent basins fits into the broader picture MAP generalization is shown in figure 10.

Figure 11 summarizes both the snow and no-snow small glacial data in terms of the centers of the parallelograms. Each dot represents a center of a parallelogram such as the two shown in figure 9. Each such parallelogram represents a "balance" area as indicated by close to complete disappearance of snowpack (i.e., small glaciers or snowfields). Each "x" represents the center of a parallelogram where even the higher elevation portions of the basin showed no snow (indicative of melt exceeding accumulation). Thus, the purposes set forth in section 2.4.2.1 are fulfilled. Each individual "." and "x" has a subscript which identifies the drainage basin outlined on figure 10. These subscripts are:

B. Baranof River Drainage
T. Takatz Creek Drainage
G. Green Lake Drainage
S. Sawmill Creek

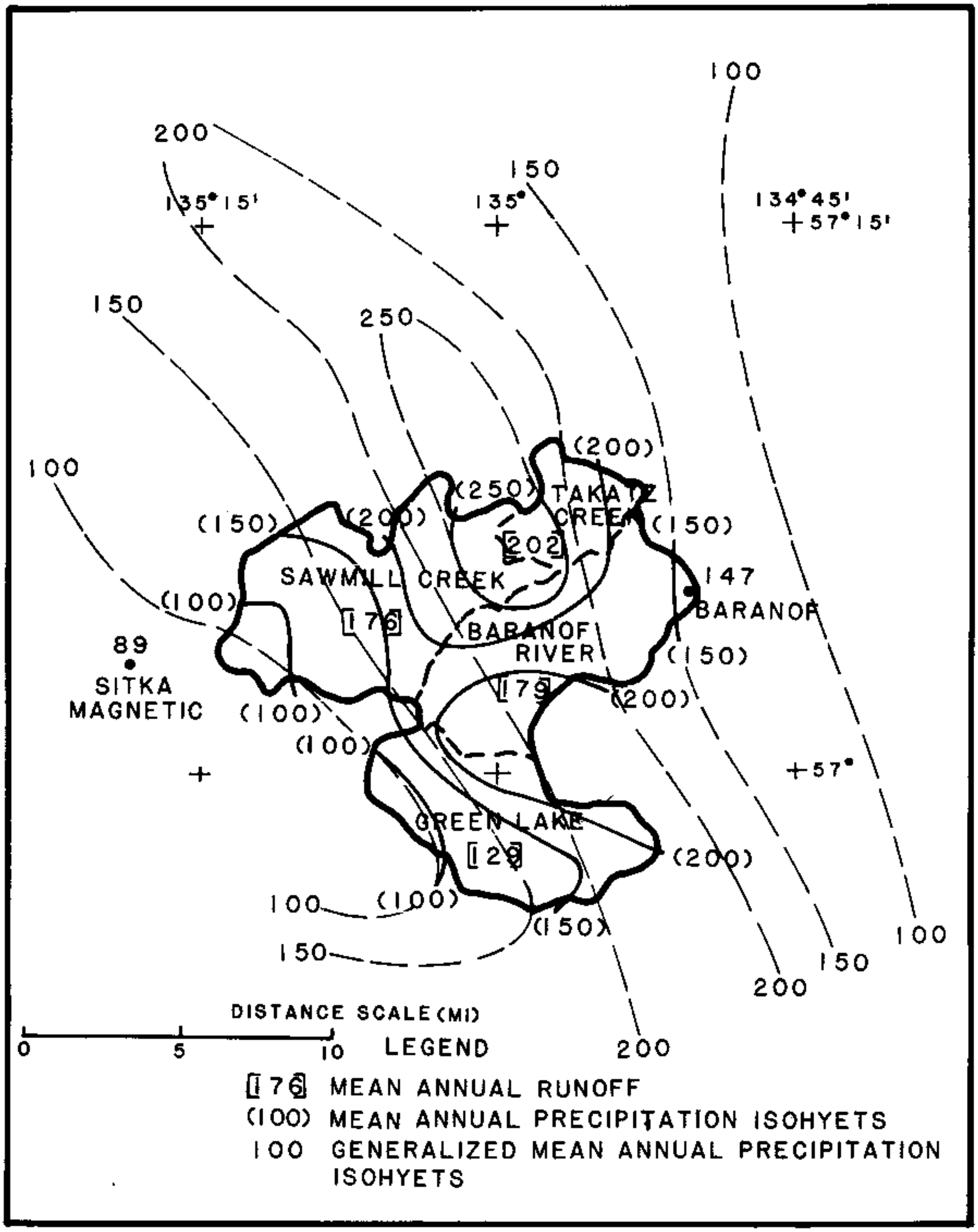

Figure 10.—Analysis of mean annual precipitation (inches) with adjoining basin runoff as input.

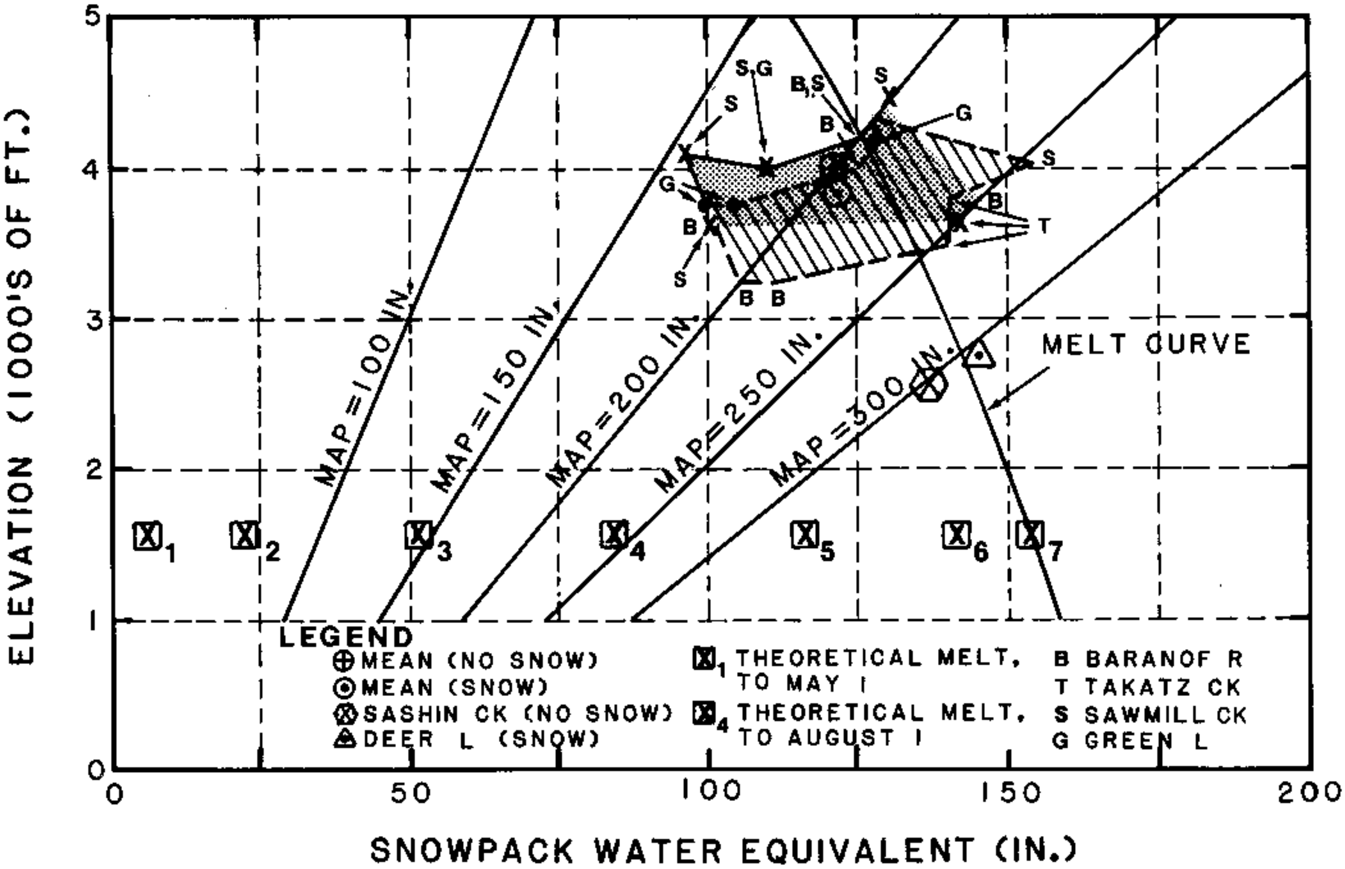

Figure 11.--Melt curve from balanced areas.

An enveloping area is outlined by connecting all the "snow" means (purpose c. under 2.4.2.1) and another doing the same with the "no-snow" means (purpose b. under 2.4.2.1). Overall means, giving each point equal weight, are shown on figure 11.

The Deer Lake and Sashin Creek drainages near the southern end of Baranof Island provide additional useful information for the placement of the melt curve at lower elevations. Mean runoff from both basins is quite similar, 291 in. (7391 mm) for Deer Lake and 284 in. (7214 mm) for Sashin Creek. The mean elevation of Deer Lake is 1,300 ft (396 m) with a small area above 3,000 ft (914 m) while Sashin Creek's mean elevation is 1,130 ft (344 m) with the highest elevations just barely 2,000 ft (610 m). The runoff values based upon analyses in other areas of large mean annual precipitation in the study area suggest that a portion of each basin must have MAP values above 300 in. (7620 mm). Deer Lake has a tiny snow-covered or glaciated area between about 2,500 to 3,000 ft (762 to 914 m). Sashin Creek has no perennial snow cover. The compositing of these data provides good evidence of the excessive MAP necessary to allow enough snow cover below 3,000 ft (914 m) to last through the long melt season at such elevations.

The "no-snow" Sashin Lake and the "snow" Deer Lake data are shown on figure 11 as data that help define the curve at lower elevations. No other lower-elevation areas exist with values of MAP high enough to provide additional data input for the lower elevations. That is, unusually large MAP amounts are needed for elevations as low as 2,500 ft (762 m) to reach near glacial conditions because of the shortened accumulation season and, consequently, long melt season.

The tentative melt curve (based upon the data shown) is drawn considering both the "snow" and "no-snow" means. However, preference is given the "snow" or balanced data. This is particularly true for the composite of Baranof River, Takatz Creek, and adjoining data. For the upper portion of the curve, too much weight to the "no-snow" data would result in a rapid dropoff of melt with elevation. That is, smooth extrapolation beyond the snow and no-snow mean would result in an elevation of no melt that would be unrealistically low in relation to prevailing free-air temperatures.

2.4.2.5 Theoretical Low-Elevation Melt Curve Fix. A degree-day ($\geq$ 32° F or 0°C) melt factor* of 0.05 per day was adopted for use at low elevations in southeast Alaska to help position the "potential" melt curve at low elevations. The main basis for the adoption of a factor of 0.05 was the mean estimated May 15 to June 15 reduction in snowpack water equivalent at the 1,000 ft (305 m) upper Long Lake drainage. The mean reduction in water equivalent was 23.7 in. (602 mm) with a range from 17 to 33 in. (432 to 838 mm). Using an average 1,000-ft (305-m) free air temperature of 50.5°F (10.3°C) for the May 15 to June 15 melt period with the mean 23.7 in. (602 mm) melt gives a degree-day melt factor of a little over 0.04). Since some other individual computations indicated somewhat higher factors, a 0.05 melt factor was adopted.**

Using the adopted 0.05 degree-day factor with degree days above 32°F (0°C) from the data at the 950-mb level of table 4 results in successive melt amounts shown plotted at the 950-mb level (approximately 1600 ft.) on figure 11. The total computed theoretical melt for the season is 154 in. (3912 mm). This value phases in quite well with the other data of figure 11 to help establish the melt curve.

2.4.2.6 Alternate Determination of Shape and Magnitude of Melt Curve From Temperature, Streamflow, and Snow Course Data. Temperature, streamflow, and snow course data can give guidance to the shaping and/or magnitude of both the total seasonal melt curve or to portions of it.

The temperature data (fig. 7) were used in combination with clues from streamflow and snow course data. The sloping dashed lines on figure 12 come from this combined use of data. The shaping placement of these curves involve both data and the following assumptions or working hypotheses.

a. The decreasing length of melt season with elevation means that a curve placed on this figure to represent the beginning or ending of a month must slope toward the left side of the figure with increasing elevation. This has to be true since, with the prevailing decrease in temperature with elevation, the melt season starts later and ends earlier (the

*On an empirical basis the degree-day melt factor is defined as the melt in inches per day divided by the total degree days above 32°F (0°C) for the melt period.

**Personal communication (Anderson 1977) suggests the melt factor in Alaska should be less than the 0.08 characteristic of the mainland United States.

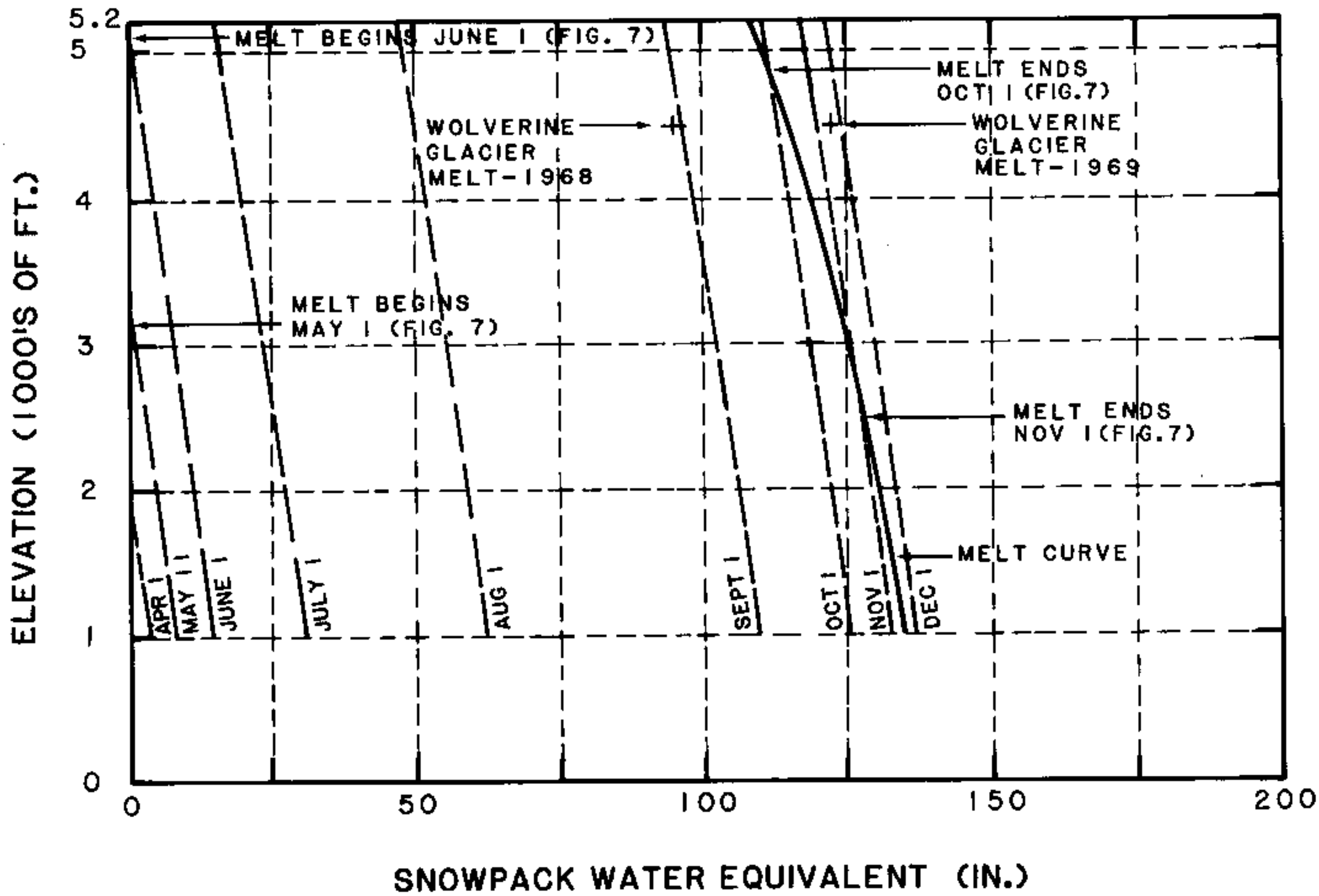

Figure 12.--Alternate estimate of melt curve with supporting data.

length of the season is shorter) as elevation increases.

b. For the placement of these dashed sloping lines (i.e , the relative magnitude of one month's melt to the adjoining months) the following must be noted:

1. Streamflow from selected basins, particularly if just partially glaciated, can provide some good clues for a melt reasonably early in the season. For such basins, the loss of contributing areas of the basin as the melt season progresses, however, decreases the usefulness of streamflow data for estimating melt beyond the first month or two of the melt season, unless some reliable estimate of contributing portion can be made.

2. If the extent of glaciation on a drainage is very large, the usefulness of such basins for melt estimates is also hindered, in this case, due to the thickness of the snowpack making the relation of runoff to melt less exact (e.g., storage, pondage, etc., become problems). In particular, early season melt estimates for such basins are on the low side. For extensively glaciated basins, the later season melt prior to loss of contributing area is the most useful.

Some assumptions and adjustments must be made in the use of stream flow to estimate the total month-by-month melt throughout the season because of the difficulty mentioned in b. above. These assumptions and/or adjustment techniques are:

a. An assumption of approximate asymmetry of seasonal snowmelt is used. That is, the runoff and other data providing a placement of the monthly melt curves prior to July (since beyond June decreased contributing area for nearly all basins reduces their usefulness), we assumed beyond August (see sect. 2.4.2.6.2) the monthly magnitude of melt will be approximately a "mirror image" of the melt prior to July. For example, September is assigned the same (or approximately the same) melt as May, October the same as April, etc.

   Theoretical computations of melt tend to support this approximate symmetry assumption of melt. See for example, the spacing of the theoretical melt points shown in figure 11.

b. For the range of elevations with which we are concerned, a month's melt is assumed constant with elevation. This simplifying assumption is tied to the fact that we use data such as streamflow which, in most cases, is an integration of melt across several thousand feet variation in elevation. If we needed to extend our relations above 5,000 ft (1,524 m) the trend of the monthly melt must be such that melt becomes zero at some elevation well above 5,000 ft (1,524 m).

2.4.2.6.1 **Spacing of April, May, and June melt curves.** The dashed lines of figure 12 give monthly increments of melt. An anchor for spacing the dashed monthly melt lines on figure 12 was the estimated melt for the month of June. There are several reasons why June melt makes a good anchor providing one chooses appropriate basins for estimating melt. June is late enough in the melt season for the higher elevations in the chosen basins to be producing melt. Yet, it is not so late that the lowest elevations have already ceased contributing melt due to loss of snowpack.

One method for estimating monthly snowmelt involved individual yearly estimates. This was done for five common years of record, i.e., 1960-61 through 1964-65 for five basins. The method uses an index station for low-elevation rainfall. The ratio of basin runoff for the season to the index station's precipitation for the same period relates basin runoff to the index station's precipitation. Then, the month-by-month runoff is compared to the rainfall according to this relation. Subtraction of the estimated basin precipitation (that comes from the ratio method) from the basin runoff gives, if negative, the storage and, if positive, the snowmelt contribution runoff. Table 8 shows the estimated monthly snowmelt determined from this procedure for four nonglaciated basins and one partially glaciated basin, the Baranof River drainage.

Table 8.—Mean estimated monthly snowmelt runoff in inches (mm) by basins for five seasons, 1960-61 through 1964-65

Basin	Average basin elevation	April in.	April mm	May in.	May mm	June in.	June mm	July in.	July mm	August in.	August mm	September in.	September mm
Perserverance Creek	1340	1.7	43	5.3	135	5.1	130	1.5	38	--	--	--	--
Fish Creek nr. Ketchikan	1800	1.3	33	4.2	107	10.8	274	3.8	97	--	--	--	--
Manzanita Creek	1300	2.6	66	5.8	147	9.1	231	5.5	140	--	--	--	--
Winstanley Creek	1730	0.6	15	4.1	104	9.3	236	4.8	122	--	--	--	--
Baranof River	2000	0.9	23	7.0	178	16.1	409	14.2	361	4.2	107	1.3	33

The slightly glaciated Baranof River drainage is especially important for estimating June snowmelt, because the problem of contributing area is of less concern than with the other basins used. Yet, the Baranof basin is not so extremely glaciated for other glacier related problems to be introduced. Table 8 shows the mean estimated snowmelt (in inches of water equivalent for the 5-year period for the Baranof River Drainage) for June of 16.1 in. (409 mm).

An alternate less time-consuming method for estimating snowmelt was tested using Baranof River data. This involved runoff data as shown for the Baranof River, table 9. The 12-yr period summarized includes the same five years used in the other method of estimating snowmelt.

In order to estimate snowmelt by the alternate method, the mean June runoff shown for Baranof in table 9 needs to be adjusted for the rainfall contribution. For this, we use the average June contribution to annual precipitation from table 6. The June precipitation is 4.28 percent of the MAP. For application of this percent, we take a MAP value of 206 in. (5232 mm) for the Baranof River drainage from our MAP analysis (fig. 6). The 4.28 percent times 206 in. (5232 mm) gives 8.8 in. (224 mm). Based upon the 1960-65 mean June Baranof runoff of 27.26 in. (692 mm), the subtraction of the estimated basin rainfall of 8.8 in. (224 mm) leaves an estimated snowmelt runoff of 18.5 in. (470 mm). Considering the differences in the two methods and the different assumptions in each, this 18.5 in. (470 mm) compares quite favorably with 16.1 in. (409 mm) of estimated snowmelt from the first method (table 8). Using the 12-yr period (same 5-yr period as in table 9 plus available data since 1965), again the 8.8 in. (224 mm) subtracted from the longer record (12-yr) mean June runoff of 26.6 in. (676 mm) leaves 17.8 in. (452 mm) as the estimated mean June snowmelt contribution of runoff.

Table 9.--June runoff for the Baranof River

Year	Runoff in.	Runoff mm
1961	33.15	842
1962	27.86	708
1963	17.33	440
1964	34.12	867
1965	23.82	605
Mean 1961-65	27.26	692
1966	23.80	605
1967	29.25	743
1969	33.62	854
1970	21.65	550
1971	27.61	692
1972	22.85	580
1973	24.19	614
Mean 1961-73 (1968 missing)	26.62	676

Since the less time-consuming second method applied to the Baranof River data compared quite favorably with the more time-consuming method, the second method was applied to additional more glaciated basins for estimates of June snowmelt. The results are summarized in table 10.

Table 10.--June snowmelt estimate for various partially glaciated basins

Basin	Mean June runoff in.	Mean June runoff mm	Period of record used	Estimated generalized MAP in.	Estimated generalized MAP mm	Estimated rain portion of runoff in.	Estimated rain portion of runoff mm	Estimated mean June snowmelt in.	Estimated mean June snowmelt mm
Mendenhall R.	23.59	599	1966-74	175	4445	7.49	190	16.4	409
Lemon C.	25.33	643	1961-73	150	3810	6.42	163	18.9	480
Herbert R.	20.75	527	1967-72	155	3937	6.63	168	14.1	358

From the estimated melt for the month of June by the two methods for Baranof River and by the one method as summarized in table 10 for the other three drainages, an adopted average June snowmelt of 0.5 in. (12.7 mm) per day or 15 in. (381 mm) for the month appears to be a realistic amount. The symmetry assumption (see 2.4.2.6), is used to apply approximately 15 in. (381 mm) to September. Computations of estimated melt for Mendenhall Basin for September (not all of this basin is glaciated), discussed in section 2.4.2.6.2, (table 11) resulted in 12.8 in. (325 mm). Considering that about 0.8 of the Mendenhall

River basin is glaciated*, the estimated 16.0 in. (406 mm) is in good agreement with the symmetry assumption of about 15 in. (381 mm).

Table 11.—Estimated snowmelt runoff for Mendenhall River drainage

Month	Mean runoff in.	Mean runoff mm	Estimated basin precipitation in.	Estimated basin precipitation mm	Estimated snowmelt runoff in.	Estimated snowmelt runoff mm
May	6.27	159	9.61	244	--	--
June	23.59	599	7.49	190	16.10	409
July	37.81	960	9.94	252	27.8°	708
August	47.89	1216	12.95	329	34.94°°	887
September	32.44	824	19.65	499	12.79	325
October	15.21	386	26.76	680	--	--

°Adjusts to 34.8 in. (884 mm). See text.
°°Adjusts to 43.7 in. (1110 mm). See text.

With an adopted 0.5 in. (12.7 mm) per day for June snowmelt, the placement of the dashed monthly melt curves on figure 12 comes from the following sequence of steps:

a. Based upon figure 7, at an elevation of 5,200 ft (1,585 m) melt will begin on June 1.

b. From figure 7, May 1 melt begins (with no earlier melt) at about 3,100 ft (945 m).

c. May melt from partially glaciated basins is estimated as approximately 0.5 of June's melt**. Therefore, May's melt is assumed to be 7.5 in. (190 mm).

d. From previous working assumption (for elevation span of concern) we use constant monthly increments.

e. The May melt, 7.5 in. (190 mm), is scaled off at 3,100 ft (945 m). This now gives a point through which the June 1 dashed line can be extended from its intersection point with the ordinate at 5,200 ft (1,585 m). The line is drawn and extended to 1,000 ft (305 m).

g. A parallelling line, scaled off to the 15 in. (381 mm) June melt, is extended to 1,000 ft (305 m) for the May melt curve.

*That is, perhaps nearly 0.2 of basin does not contribute in September. Assuming 0.2 applied for the noncontributing portion in September, the estimated melt (if 100 percent of basin were contributing) would be about 16 in. (406 mm), that is, 12.8 divided by 0.8.

**Table 8 shows Baranof River about 42 percent, but consideration of additional basins suggests about 50 percent.

2.4.2.6.2 **Spacing of melt curves for July, August, and subsequent months.** Estimated snowmelt from the Mendenhall River drainage (fig. 4) plus comparisons with other basins form the basis for estimating the July and August melt. A summary of the estimated mean monthly (8 years of data) snowmelt runoff with supporting data for the Mendenhall River drainage is given in table 11.

The estimated basin precipitation (table 11) comes from the generalized MAP (fig. 4) and mean monthly percents of MAP from table 6. These values are: MAP - 175 in. (4445 mm); mean monthly percents of 5.49 for May, 4.28 for June, 5.68 for July, 7.40 for August, 11.23 for September, and 15.29 for October. Using these values, an estimated snowmelt runoff for each month was determined. These results indicate a net storage in May and October. Thus, for practical purposes the snowmelt season is June through September. The unadjusted July and August computed values of 27.87 in. (708 mm) and 34.94 in. (887 mm), respectively, were increased by 25 percent. This comes about through estimating that with the basin approximately 0.8 glacier covered, there is 0.2 basin that likely is non-contributing in July and August. Therefore, dividing the 27.87 in. (708 mm) for July and the 34.94 (887 mm) for August by 0.8 gives the 34.8 in. (884 mm) for July and 43.7 in. (1110 mm) for August. This combined July, August total of approximately 78.5 in. (1994 mm) is reapportioned for convenience on the basis of an even 1 in. (25.4 mm) per day for July and 1.5 in. (38.1 mm) per day in August giving a July plus August total melt of 77.5 in. (1968 mm). These are thus estimated melt amounts if 100 percent of the basin were contributing melt rather than 80 percent.

For months following August, the symmetry assumption discussed under section 2.4.2.6 is used. Thus, for September ("symmetry month" for June), we adopt 0.5 in. (12.7 mm) per day; for October (May's symmetry month) 0.25 in. (6.35 mm) per day; for November (April's symmetry month) 0.125 in. (3.18 mm) per day.

2.4.2.6.3 **Suggested shape and magnitude of melt curve from composite of empirical data.** With adopted values of monthly melt through the season and slope of the melt curves determined, one factor remains for firming a melt curve by this alternate method. This factor concerns dates of ending of melt with elevation. According to figure 7, November melt prevails up to 2,500 ft (762 m) and October melt extends to about 4,900 ft (1,494 m). From results of all the data discussed in this section we define a melt curve independent of the melt curve discussed in sections 2.4.2.4 and 2.4.2.5. This independently determined melt curve is shown on figure 12 with supporting data.

2.4.2.7. Snow Course Data as a Check. Since prevailing temperatures near the south coast of Alaska during the melt season are quite similar to our study area, we can use snow course data from Wolverine Glacier (2-yr record) at an elevation of 4,430 ft (1,350 m) as a rough check on placement of the melt curve. Long-duration melt data were available for both 1968 and 1969 at the 4,430-ft (1,350 m) site.

In June 1968, a 184 in. (4674-mm) snow pack had 95.7 in. (2431 mm) of water equivalent. By September 15, this had reduced to 41 in. (1041 mm) of snow or 21.3 in. (541 mm) of water equivalent, giving a total reduction in water equivalent of 74.4 in. (1890 mm). On June 3, 1969, a 207-in. (5258-mm) snow cover with a water equivalent of 107.1 in. (2720 mm) reduced to 5.9 in. (150 mm) by September 14. These values are plotted on figure 12 after adding 20 in. (508 mm) for expected melt prior to June at the 4,430-ft (1,350-m) elevation.

The adopted melt curve on this figure fits in the range of this independent data quite well.

2.4.2.8. Adopted Melt Curve. Two separate methods of estimating a melt curve have been discussed. The estimated melt curve from one method (sec. 2.4.2.4 and 2.4.2.5) is shown on figure 11, the other (section 2.4.2.6), on figure 12. Figure 13 shows the adopted melt curve transformed so that MAP is the abcissa and elevation is the ordinate. An area, rather than a line, is used to separate melt from glaciation.

2.4.3 Use of Melt Curve for Adjustments to First Approximation Mean Annual Precipitation Chart

In the beginning of section 2.4 we introduced the concept of using small snowfields or glaciers for adjusting the first approximation MAP map. We pointed out the need for a relation of MAP to accumulated snowpack with elevation and a relation which tells us how much melt to expect in a season at a given elevation.

The solution of the first required relation shown in figure 8 is combined with a mean estimated melt curve to give us the combined relation in figure 13. This combination of derived relations was then used in accordance with the purpose set forth in section 2.4.2.1. To accomplish the purpose of adjusting MAP, both the existence and nonexistence of small glaciers or snowfields were thus used (as determined from U.S. Geological Survey topographic charts) to check and adjust the tentative MAP chart. Acceptance of the melt curve of figure 13 represents a "balanced" condition indicating no significant increase or decrease in snow cover. That is, the accumulated snowpack just completely melts during the warm months just as the time is reached for a new seasonal snowpack to begin accumulating.

In the area above the melt curve on figure 13, excess snowpack accumulates providing glaciation, while below the curve, all the cold season accumulated snowpack melts. On figure 13, a zone around the melt curve (sec. 2.4.2.8) is indicated representing a span of MAP of ±12.5 in. (±318 mm) to allow for a margin of uncertainty in placement of the line of demarcation or melt curve. Thus, in practical application, unless a change in the first approximation MAP analysis of 12.5 in. (318 mm) or more is indicated in a particular area, no adjustment is made.

Thus, the use of figure 13 is based on the information provided by the melt curve and where this melt curve, with a MAP span of 25 in. (635 mm) for various elevations, is intersected by various MAP lines. For example, the melt curve is intersected by the 200-in. (5080-mm) MAP line at about 4,000 ft (1,220 m) or a little higher. Thus, if an area near or slightly above 4,000 ft (1,220 m) has small glaciated areas, one should assume that the MAP in such an area ought to be close to 200 in. (5080 mm). If the first approximation analysis based on the closest data caused us to place only 150 in. (3810 mm) in such an area, from the use of figure 13, we conclude the amount ought to be increased about one-third. In addition to the type of check just described, figure 13 was also used to check against "overdoing" the amount of MAP.

The existence, or nonexistence, of small glaciated areas over various portions of our study area was evaluated in the light of figure 13 for suggested changes in the first approximation MAP chart. A representative sampling of the main adjustments made using figure 13 are:

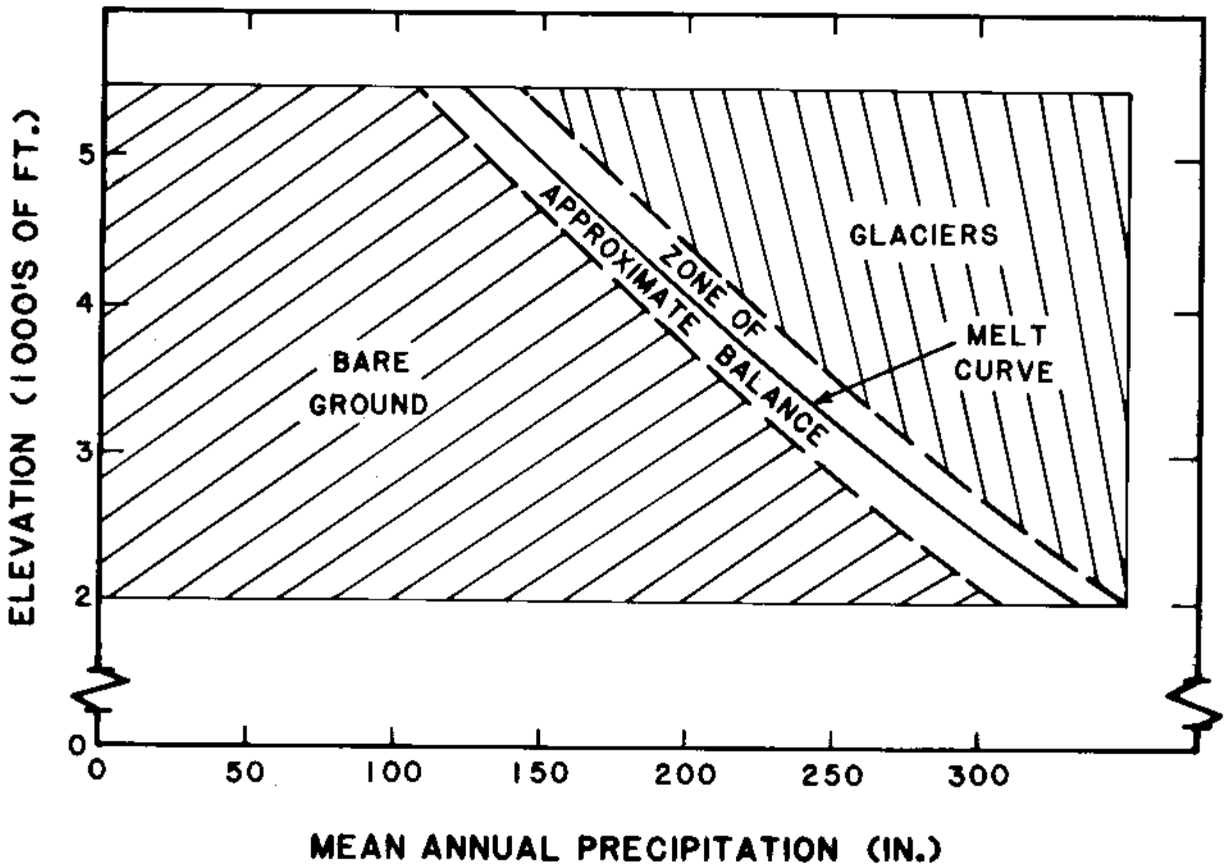

Figure 13.—Melt curve vs. mean annual precipitation and elevation for adjustments to first approximation mean annual precipitation chart.

a. North of the area of balanced analysis of figure 10 on Baranof Island, small glaciated areas exist near and somewhat below 4,000 ft (1,220 m). There are no basin runoff values in these areas suggesting what the MAP ought to be. Based upon figure 13 though, we have extended a 200 in. (5080 mm) MAP area to cover these small "balanced" snow-covered areas. We do not go as high as 250 in. (6350 mm) in this area, however, since values this high would likely contribute to more extensive glaciation than now exists.

b Examination of the topography of basins such as the Harding River, the Klahini River, and Cascade Creek jointly indicate elevations of 4,000 ft (1,220 m) or a little higher are needed for the formation of snowfields or small glaciers. A generalized MAP of about 175 in. (4445 mm) appeared adequate for explaining the small glaciated areas that exist near the higher elevations. This analysis permits the existence of some higher MAP in some portions of this